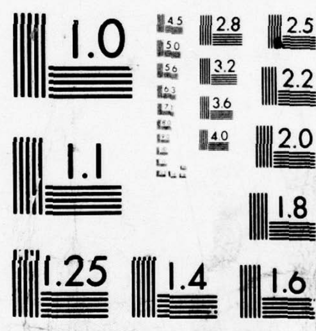
AD-A074 219 ADRIAAN VOLKER DREDGING CO ROTTERDAM (NETHERLANDS) F/G 13/3
ASSESSMENT OF CERTAIN EUROPEAN DREDGING PRACTICES AND DREDGED M--ETC(U)
DEC 78 K D'ANGREMOND, J BRAKEL, A J HOEKSTRA DAJA37-75-C-0382

UNCLASSIFIED WES-TR-D-78-58 NL

1 OF 3

AD A074219




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

# DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-78-58



# ASSESSMENT OF CERTAIN EUROPEAN DREDGING PRACTICES AND DREDGED MATERIAL CONTAINMENT AND RECLAMATION METHODS

by

K. d'Angremond, J. Brakel, A. J. Hoekstra
Adriaan Volker Dredging Company
Rotterdam, The Netherlands

W. C. H. Kleinbloesem, L. Nederlof, J. de Nekker
Rotterdam Municipal Works
Rotterdam, The Netherlands



December 1978
Final Report





Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under Contract No. DAJA37-75-C-0382
(DMRP Work Unit No. 2C14)

Monitored by Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

(18) WES

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER (14) TR-<br>Technical Report D-78-58 | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle) (6)<br>ASSESSMENT OF CERTAIN EUROPEAN DREDGING PRACTICES AND DREDGED MATERIAL CONTAINMENT AND RECLAMATION METHODS, | | 5. TYPE OF REPORT & PERIOD COVERED (9)<br>Final report, |
| | | 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s) (10)<br>K. d'Angremond, J. Brakel, A. J. Hoekstra, W. C. H. Kleinbloesem, L. Nederlof, J. de Nekker | | 8. CONTRACT OR GRANT NUMBER(s)<br>Contract No. (15) DAJA37-75-C-0382 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Adriaan Volker Dredging Company<br>Rotterdam, The Netherlands | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>DMRP Work Unit No. 2C14 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Office, Chief of Engineers, U. S. Army<br>Washington, D. C. 20314 | | 12. REPORT DATE (11)<br>December 1978 |
| | | 13. NUMBER OF PAGES<br>228 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)<br>U. S. Army Engineer Waterways Experiment Station<br>Environmental Laboratory<br>P. O. Box 631, Vicksburg, Miss. 39180 | | 15. SECURITY CLASS. (of this report)<br>Unclassified |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited. (12) 242p.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

| | |
|---|---|
| Assessments | Dredging |
| Containment areas | Environmental effects |
| Dredged material | Europe |
| Dredged material disposal | Reclamation |
| Dredges | Waste disposal sites |

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A study was made of dredging practices, reclamation methods, and environmental effects of dredging in western Europe by visiting more than twenty ports in six countries and discussing pertinent matters with knowledgeable authorities at each port. A remarkable similarity of dredging practices, reclamation methods, and dredging equipment was noted among the European ports. The productive land use of dredged material was a common goal. Contamination cont'

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE 392194 Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

79 09 24 050

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20. ABSTRACT (Continued).


CONT'

problems existed or were potential, to various degrees, at all ports, but few ports were able to assess in specific quantitative terms the status of the local contamination, much less to offer well-developed techniques for the solution of their problems. All were aware of the need for continued research into dredging practices and reclamation methods and of the need to intensify research in the area of environmental effects, particularly contamination. The need for regional and world-wide legislation to control contamination and other adverse environmental effects also was universally recognized.

Technical details of describing, increasing the density of, disposing, and making productive use of dredged material were discussed, often by using the widely accepted techniques employed in the Rotterdam Harbor as examples.

Conventional and special dredging equipment is described and contamination of dredged material and environmental effects is discussed in detail in this report.




Unclassified
SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

THE CONTENTS OF THIS REPORT ARE NOT TO BE USED FOR ADVERTISING, PUBLICATION, OR PROMOTIONAL PURPOSES. CITATION OF TRADE NAMES DOES NOT CONSTITUTE AN OFFICIAL ENDORSEMENT OR APPROVAL OF THE USE OF SUCH COMMERCIAL PRODUCTS.

## PREFACE

Under Contract No. DAJA37-75-C-0382, dated 31 July 1975, the U. S. Army Engineer Waterways Experiment Station (WES), Environmental Laboratory (EL) commissioned a study entitled "Assessment of Certain European Dredging Practices and Dredged Material Containment and Reclamation Methods." To accomplish the study, a group was formed, as follows:

| Member | Position and Employer |
|---|---|
| K. d'Angremond | Head of the development department of Adriaan Volker Dredging Company |
| J. Brakel | Member of the research department of Adriaan Volker Dredging Company |
| A. J. Hoekstra | Director of Adriaan Volker Dredging Company |
| W. C. H. Kleinbloesem | Manager of maintenance dredging harbor department of Rotterdam Municipal Works |
| L. Nederlof | Research coordinator of the harbor department of Rotterdam Municipal Works |
| J. de Nekker | Chief of the harbor department of Rotterdam Municipal Works |

Special contributions to the report were made by:

| | |
|---|---|
| A. J. de Groot | Institute of Soil Fertility at Haren |
| J. R. Willet | Advies Bureau Arnhem at Arnhem |

The contracting party on behalf of the study group was Adriaan Volker Dredging Company.

During the study a large number of Government Offices, port authorities, and institutes were visited. The kind cooperation of all concerned is highly appreciated.

The contract was conducted as part of the Dredged Material Research Program (DMRP) Disposal Operations Project, Mr. C. C. Calhoun, Jr., Manager. Dr. Hoyt Lemons of the European Research Office was Contracting Officer.

Directors of WES during the study and preparation of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONTENTS

CONTENTS

## ASSESSMENT OF CERTAIN EUROPEAN DREDGING PRACTICES AND DREDGED MATERIAL CONTAINMENT AND RECLAMATION METHODS

## PART I: INTRODUCTION

### Background

1. In March 1973, the U. S. Army Engineer Waterways Experiment Station (WES) was directed by the Office, Chief of Engineers, U. S. Army, to conduct a research program on the disposal of dredged material. The Dredged Material Research Program (DMRP) has as its objective to provide more definitive information on the environmental aspects of dredging and dredged material disposal operations and to develop technically feasible, environmentally sound, and cost-effective dredging and disposal alternatives, including consideration of dredged material as a manageable resource.

2. The operational and engineering aspects of dredging and dredged material disposal are being considered primarily within the Disposal Operations Project (DOP) (one of the four projects comprising the DMRP). The work conducted by the DOP has many facets and includes research into containment area operations, dredged material densification, disposal area reuse, treatment of contaminated material, turbidity prediction and control, and basic dredging and related equipment.

3. It is recognized that the state of the art and the state of the practice of many of the areas named in the preceding paragraph are considerably more advanced in Europe than in the United States. It was therefore decided to assess systematically pertinent European experience and expertise in the expectation that such an assessment and the resulting report would serve as a valuable reference for the efficient and economical planning and conducting of the DOP research tasks. This report is the result of that decision.

### Purpose

4. The purpose of this study was to investigate and report on the

current dredging and disposal practices in Europe, with emphasis on their relevance to the DMRP.

## Scope

5. The study was a state-of-the-art analysis. It dealt only with existing engineering and operational aspects of dredging and disposal practices. It entailed no research to develop new practices or data.

6. To collect information on dredging practices and reclamation methods, it was decided to visit the authorities responsible for the maintenance of major ports and waterways in Western Europe. Although dredging operations are carried out for minor ports too, and even for projects not related to navigation, it was felt that most of the systematic experience was obtainable from the deep water ports in western Europe. More than twenty ports in six countries were visited by a delegation from the study committee. The authorities consulted are listed in Table 1. Contact was also established with other Governmental Agencies and research institutes that were expected to be able to make a valuable contribution to the study. These agencies and institutes are also mentioned in Table 1.

7. Since a number of ports and/or dredging projects were visited, it was felt useful to present the main facts and statistics connected with those projects in some detail (Appendix A). In addition, the statistical facts relevant to dredging and disposal practices at each port are summarized in Table 2. These findings are sometimes repeated and discussed more extensively and systematically in the subsequent chapters of this report dealing with the main subjects of the study. In Parts IV and V on dredging equipment, mention also is made of certain equipment and development in equipment originating outside Europe.

Table 1

List of Port Authorities, Agencies, and Institutes Visited

| Country | Name | Address | Remarks |
|---|---|---|---|
| Belgium | Stad Antwerpen Technische Dienst van het Havenbedrijf | Kaai 63, Antwerp Belgium | |
| France | Port Autonome de Bordeaux | 152, Quai de Bacalan, Bordeaux France | |
| | Port Autonome de Dunkerque | P. O. Box 6534, Dunkerque, France | |
| | Port Autonome du Havre | P. O. Box 1413, Le Havre, France | |
| | Port Autonome de Marseille | P. O. Box 2 Marseille, France | |
| | Port Autonome de Rouen | 34, Blv de Boisguilbert Rouen, France | |
| W. Germany | Frei und Hansestadt Bremen Hansestadt Bremisches Amt | Bussestrasse 27 Bremerhaven, W. Germany | |
| | Freie und Hanse-stadt Hamburg, Behörde für Wirt-schaft und Verkehr Strom und Hafenbau | Dalmannstrasse 1-3 Hamburg-11 W. Germany | |
| The Netherlands | Adviesbureau Arnhem | Oeverstraat 20, Arnhem, The Netherlands | Consultant |
| | Delft Hydraulics Laboratory | P. O. Box 177 Delft, The Netherlands | |
| | Municipality of Amsterdam, Dept. of Public Work | Wibautstraat 3, Amsterdam | |
| | Municipality of Rotterdam, Harbor Department | Veemarkt Rotterdam, The Netherlands | |

(Continued)

Table 1 (Concluded)

| Country | Name | Address | Remarks |
|---|---|---|---|
| | Nederlands Instituut voor Onderzoek der Zee (NIOZ) | Texel, The Netherlands | General |
| | Rijksdienst voor de IJsselmeerpolders | Smedinghuis, Lelystad | |
| | Rijksinstituut voor Visserij Onderzoek (RIVO) | Haringkade 1 IJmuiden | Research on Commercial Fishery |
| | Directie Benedenrivieren | Spuiboulevard 344 Dordrecht | |
| | Directie Noordzee | Nijverheidsstraat 1 Rijswijk (Z.H.) | |
| | Deltadienst afd. Milieuonderzoek | Raadhuisstraat 9, 's Heer Arendskerke | |
| | Deltadienst afd. Nieuwe Werken Oost | P. O. Box 167, Bergen op Zoom | |
| | Studiedienst IJmuiden | De Wetstraat 3, IJmuiden | |
| | Rijkswegenbouw *Laboratorium* | v. Mourik Broekum-weg, Delft | Road Research Laboratorium |
| Portugal | Administraçao Geral do Porto De Lisboa | Junqueira 94 Lisbon | |
| | Direççao Geral de Portos | Doca de St Amaro Lisbon | |
| United Kingdom | British Transport Docks Board | Pierhead Building Cardiff | |
| | British Transport Docks Board | P. O. Box 1 Hull | |
| | The Mersey Docks & Harbour Cy | Pierhead Liverpool | |
| | Port of London Authority | Thames House Gallions Entr. London | |

**Table 2**

Summary of Pertinent Findings at Western European Ports

| Port | Annual Dredging, $m^3$ Maintenance | Capital | Type of Dredged Material Maintenance | Capital | Dredging Equipment* | Is Dredged Material Used in Reclamation? | Are Special Dewatering Techniques Employed? | Status of Contamination |
|---|---|---|---|---|---|---|---|---|
| Antwerp | 2,500,000 | | | | Bucket, grab, land reclamation dredger, barges | Yes | No | Not known |
| Bordeaux | 12,000,000 to 16,000,000 | 1,500,000 to 4,000,000 | Sand, mud | Sand, mud | Various | Yes | Mud, yes; sand, no | Slight contamination |
| Dunkirk | 2,000,000 | 18,000,000 | Sand, mud | Sand, mud | Trailing suction hopper dredges plus others | Yes | No | Part of the material dredged in maintenance is polluted |
| Le Havre | 1,500,000 | Varies widely | Mud | Sand, sometimes with gravel | | Yes | No | Not known |
| Marseille | 0 | 14,000,000 (near Fos) | -- | 30% silt 30% sand 20% gravel | Hopper dredges | Yes | No | Not polluted |
| Rouen | 3,750,000 to 4,500,000 | 1,250,000 to 1,500,000 | Sand, mud | Sand, gravel | Bucket, trailing hopper, cutter suction dredges | Yes | Yes | Material from maintenance dredging is believed to be polluted |
| Bremerhaven | 1,600,000 harbor; 7,000,000 estuary | | Sand, mud | | Trailer suction hopper dredge | Yes | No | Not known |
| Hamburg | 2,200,000 harbor; 8,500,000 downstream | 1,000,000 to 3,000,000 | 65% mud, 35% sand | Sand | Bucket, grab, reclamation, and trailing suction hopper dredges; barges | Yes | Mud, yes; sand, no | Believed to be contaminated with heavy metals and pesticides |
| Rotterdam | 18,000,000 | | Fine | | Trailing suction hopper, bucket, and reclamation dredges, barges | Yes | Yes | |
| Lisbon | 2,000,000 | | Mud | | Bucket and grab dredges; barges | No, but being considered | -- | Increasing |
| Cardiff | 4,000,000 | 0 | Fine sand, silt | | Trailing suction hopper and grab dredges | No | -- | Insignificant contamination |
| Hull | 4,000,000 | | Fine sand, mud | | Grab and trailing suction hopper dredges | No | -- | Probably not polluted |
| Liverpool | 2,000,000 river; 1,500,000 docks | | Very fine sand, mud | | Trailer | No | -- | Some mud is polluted |
| London | 700,000 | 500,000 | Fine sand, mud, gravel, silt with sand | | Grab dredges, barges, reclamation dredges | Yes | Yes | Insignificant contamination |

* For convenience, terminology not common in the U. S. is listed and explained in the Glossary (Appendix I).

## PART II: DESCRIPTION OF DREDGED MATERIAL

8. In this part of the report, a brief description is given of a system for classifying soils for dredging purposes, and mention is made of the factors used in characterizing dredged material. In addition, the material encountered in maintenance dredging in Rotterdam Harbor is described in some detail, while the maintenance dredging material in areas outside the Rotterdam area is only generally described.

### PIANC System

9. A classification system for soils to be dredged has been proposed by the Permanent International Association of Navigation Congresses (PIANC) of which the United States is a member country. The system is given in Appendix B. The physical properties of the soil that supposedly influence the output of a dredge are listed, as well as the laboratory tests needed to acquire the numerical values. Methods to obtain samples of the different materials are mentioned as well as a general outline of the kind of dredging equipment needed under different soil conditions. The PIANC System reflects to a great extent the current practice in Holland, although the information forwarded by the client to the contractor is usually less elaborate than would result if all the recommendations were followed. The use of the PIANC system by the dredging industry is recommended for the following reasons:

- a. It is specifically composed for the needs of the dredging industry.
- b. It is international.

### Characterization of Mud, Sand, and Clay Dredged Material

10. In maintenance dredging the materials to be dredged are mostly mud and fine sand. Mud is defined in this report as clay or silt or a mixture of both, with or without sand, having a water content higher than the liquid limit. The classification system does not list mud in

a special category, although its rheological properties are extremely important from a dredging standpoint. Because of this, one feels that soils with such a high water content should be mentioned separately. It is recommended to classify mud by:

a. Specific weight (wet density).

b. Particle analysis.

c. Viscosity as determined from tests using equipment such as a couette-type viscometer.[1]

11. The following tests are commonly performed at present on soils to be dredged:

| Soil | Test |
|---|---|
| Sand | Particle-size analysis |
| Virgin clay | Tor-vane measurement, penetrometer test, or triaxial test to obtain a cohesion strength; wet density measurement |
| Mud | In situ density is sometimes determined |

In the near future other properties of the soil to be dredged, such as the in situ density and permeability of sand and the viscosity and density of mud, will probably be measured to permit a better estimate of the output of the dredges as related to different soil materials.

## Material Encountered in the Rotterdam Harbor Area

12. Because in the following parts of the report much attention is paid to dewatering of dredged material from Rotterdam Harbor, a special effort is made to describe this material. In the harbor basins of Rotterdam Harbor, one can generally distinguish three zones (shown in Figure 1), as far as granular composition of the bottom material is concerned:

a. Harbor mouth where the coarser particles settle (20 percent is smaller than 50 μ).

b. Transitional zone of mixed material.

c. Harbor proper where the smaller particles settle (80 percent is smaller than 50 μ).

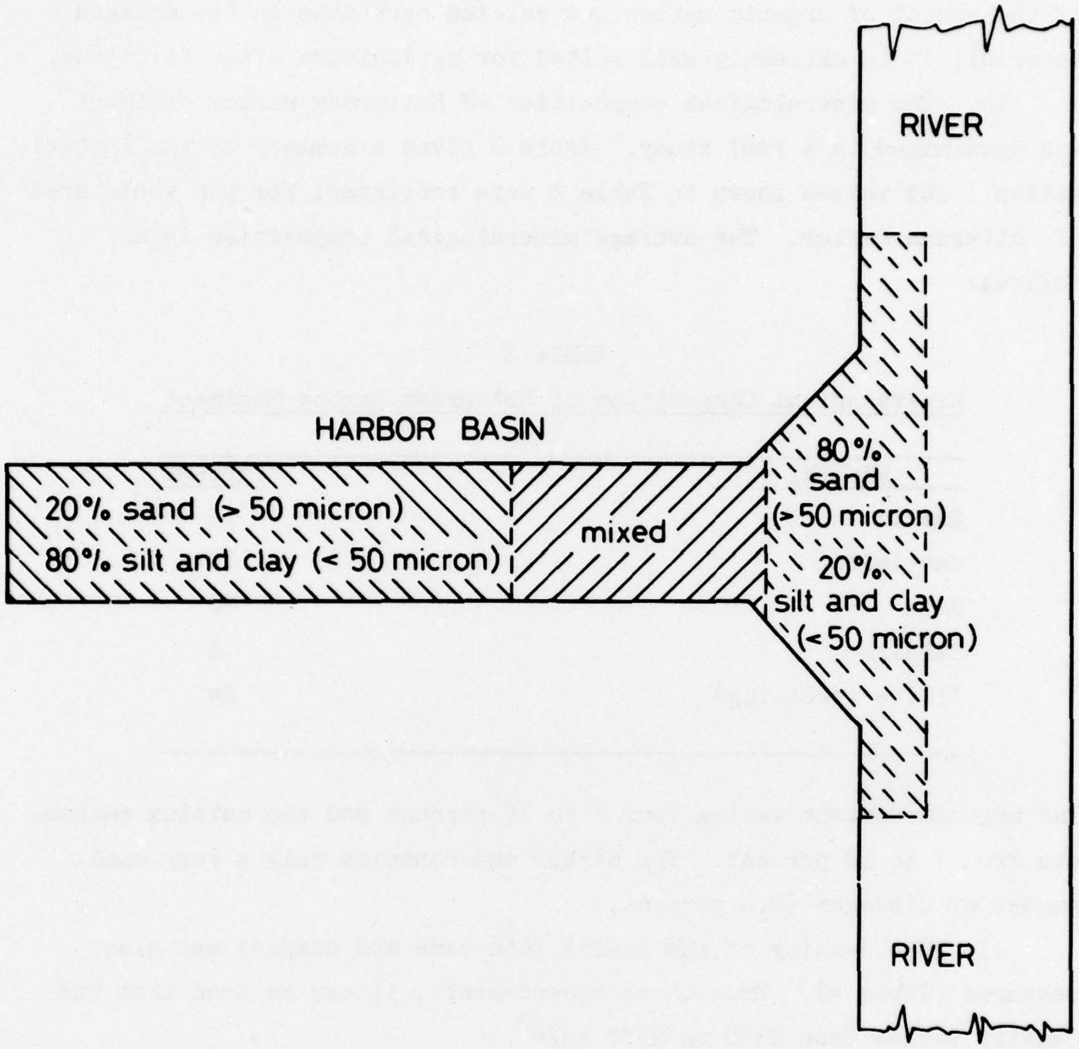



Figure 1. Sedimentation pattern in Rotterdam Harbor area

13. In the transitional zone, the bottom consists of a mixture of sand and mud. This is reflected by a comparatively low output of the trailing hopper dredges. As most of the material settles in the transitional zone, the dredging activity is mainly centered in this zone. The average grain-size composition of the material to be dredged is: 26 percent < 2 μ, 45 percent < 16 μ, and 78 percent < 50 μ. The sediment typically contains about 8 percent organic matter and 15 percent calcium carbonate ($CaCO_3$), and the pH value equals 8. The solid phase of the mud can be described as a light clay or a slightly sandy clay. Because

of the amount of organic matter and calcium carbonate in the dredged material, it is extremely well suited for agriculture after it ripens.

14. The mineralogical composition of Rotterdam Harbor sediment was determined in a 1967 study. Table 2 gives a summary of the investigation. The values shown in Table 3 were consistent for the whole area of Rotterdam Harbor. The average mineralogical composition is as follows:

Table 3

Mineralogical Composition of Rotterdam Harbor Sediment

| Mineral | Percent |
|---|---|
| Quartz | 15 |
| Kaolinite | 15 |
| Mica | 38 |
| Calcite | 8 |
| Illite (swelling) | 24 |

The organic content varies from 3 to 16 percent and the calcium carbonate from 7 to 18 percent. The harbor mud contains only a very small amount of nitrogen (0.4 percent).

15. The density of the grains from some mud samples was also measured (Table 4). From these measurements, it can be seen that the density varies from 2380 to 2570 kg/m$^3$.

## Material Encountered at Locations Outside Rotterdam

16. In maintenance dredging areas, the siltation is caused by material transported by rivers or sea currents. This means that the materials encountered are in general similar to those found in the Rotterdam Harbor area, although the composition may differ in detail. The same sorting out processes take place, i.e., the coarser particles settle nearer to the river, the finer particles in the basins. A great deal of the transport is caused by density currents. Not much exact

Table 4

Density of Harbor Mud (Grains)

| Origin | Density of Grains, kg/m$^3$ |
|---|---|
| Europoort | 2,410-2,570 |
| Botlek | 2,455-2,535 |
| le Petroleumhaven | 2,380-2,570 |
| 2e Petroleumhaven | 2,390-2,490 |
| Waalhaven | 2,400-2,560 |
| Maashaven | 2,430-2,430 |
| Rijnhaven | 2,440 |
| Merwehaven | 2,390-2,420 |
| Spoorweghaven | 2,420 |
| Binnenhaven | 2,380 |

information concerning the nature of the material to be dredged was directly available in any of the harbors visited in connection with the study; however, sometimes the grain size of some samples had been determined.

## PART III: INCREASING THE DENSITY OF DREDGED MATERIAL

17. In the dredging process, soil is necessarily mixed with water. Economical dredging requires that the soil-water mixture contain as much soil (and as little water) as practicable, consistent with efficiency and economy, in the various dredging phases. In this part of the report, the dredging process is described and discussions are presented on increasing in situ density, optimizing in-line solids concentration, and densification during the dredging process.

### The Dredging Process

18. The dredging process can be divided into two phases, pick-up (mixture formation) and transport. In the first phase the soil is loosened and becomes mixed with water. In the second phase the mixture is transported to the hopper* or barge or the disposal area. As far as mixture formation is concerned, the bucket dredge is the best piece of equipment for providing maximum solids content. If the thickness of the layer to be removed is such that the buckets can be filled completely and if this thickness persists along the whole cut, the average density of the dredged material in the buckets can be almost the in situ density. Thus, the barges alongside can be filled with a high percentage of solids.

19. In hydraulic dredges such as hopper dredges and barge unloading dredges, water has to be added to the dredged material to get a mixture that can be pumped by the centrifugal dredge pump. The construction of the draghead is of paramount importance in a hopper dredge. Good results have been achieved with modified California dragheads in sand with a high void ratio and mud, while a draghead with knives seems suitable for sands and clay (Figures 2 and 3). When pumping mud it is important to be able to regulate the amount of water to get a viscosity of the mixture that is not too high. To this end, valves have been

---

* Dredging equipment is described in Part IV.

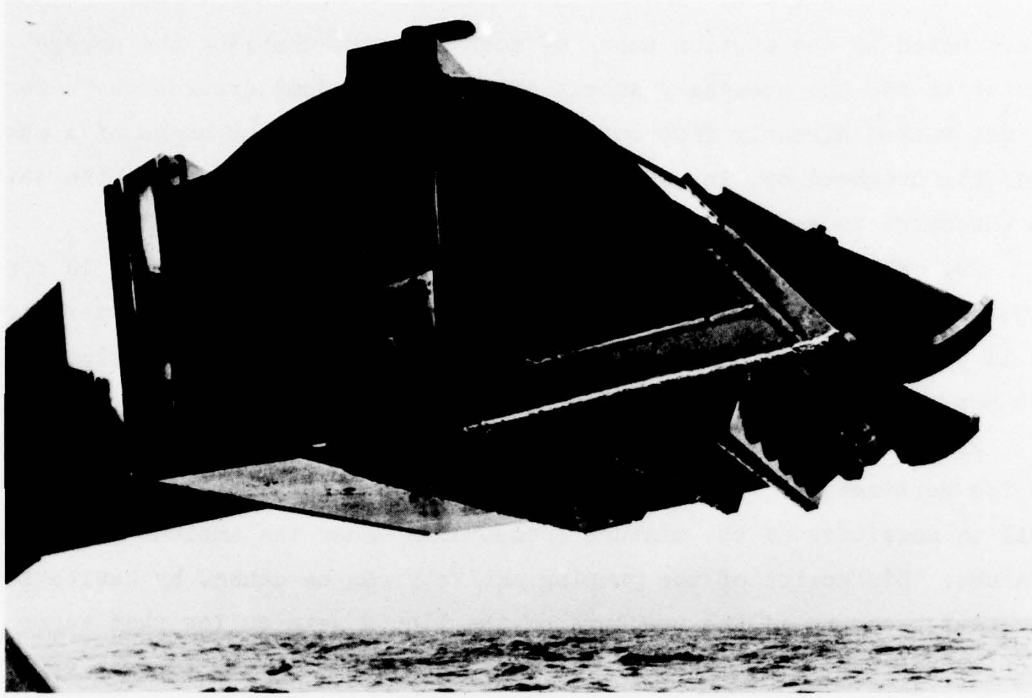


Figure 2. Draghead with knives

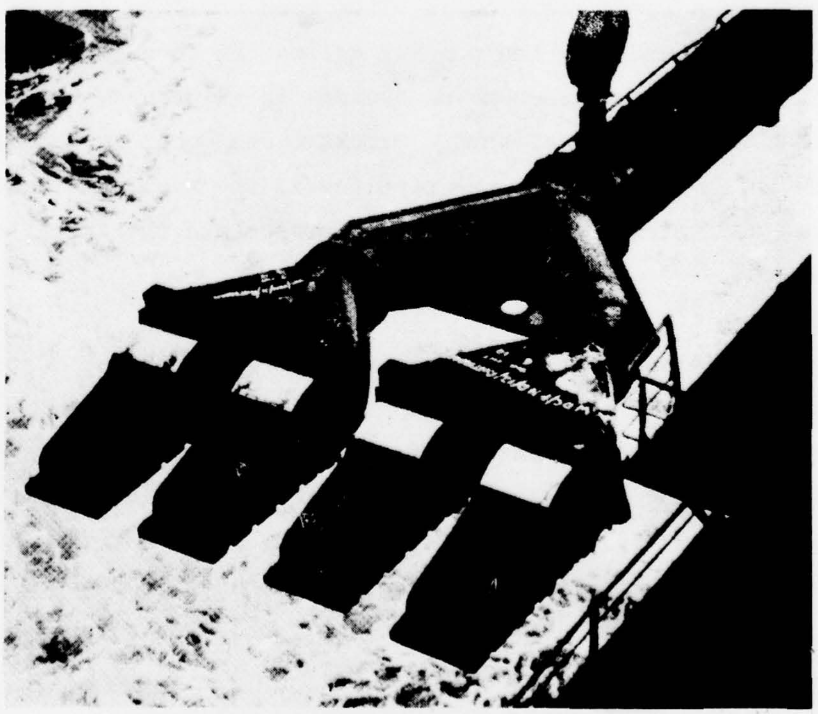


Figure 3. California draghead

constructed in the suction tubes of most dredges, enabling the dredge master to add the necessary amount of water. In some dredges the water is not sucked directly from outside, but it is jetted by means of a pump into the draghead or, in case of a barge unloading dredge, into the soil in the barge to accelerate the mixture formation.

20. Whenever the density of the mixture in a hopper dredge is considered too low, the dredged material is not pumped into the hopper, but it is pumped back into the waterway. This leads to a higher payload in the hopper, but the turbidity of the waterway increases.

21. Once the mixture is formed, the pump must be able to propel it to its destination. This means that ideally the pump should perform well at densities of the mixture encountered under the ambient circumstances. Disruption of the pumping activity can be caused by cavitation. Cavitation occurs if the pressure of the liquid gets so low that vapor bubbles are generated locally. It can cause the velocity to drop very suddenly and initiate effects like water hammer. To boost the pressure in a pump or in the higher part of a siphon, one can lower the pump or the siphon or add to the pressure (e.g., by means of a jet pump). Moving the pump to a lower position is often used nowadays (Figure 4). Another cause of hampering the pumping action can be a gas content that is too high. There are gas-removal systems in existence, the efficiency of which has not been established. Blockage can occur as a consequence of too low a flow velocity in the pipeline if the available head of the pump is not sufficient for the pumping distance and the specific material.

Personnel

22. In addition to the mechanical factors, the human factor also is very important. Without a well-trained and well-fed crew, successful operation of a dredging fleet is not possible. To help the personnel to perform their tasks, much attention has lately been given to instrumentation (Figure 5) and ergonomics. Because of wear and tear, instruments often break down; accordingly, constant maintenance is needed. For training crew members, a national dredging school was established in The Netherlands at Delfzijl.

Figure 4. Pump mounted on ladder

Figure 5. Modern instrument panel

## Instruments

23. As long as the instruments are only moderately reliable, automation of the dredges will be rather limited. The instruments used in hydraulic dredges to monitor the dredging process are generally vacuum gages and pressure gages, mostly pneumatic; lately, transducers also have been used. A velocity meter and a density meter, respectively, measure the velocity and the density of the mixture in the pipeline. In hopper dredges more attention is given nowadays to the accuracy of the

positioning by using systems like Decca Hi-fix, Sea-fix, Toran, or Trisponder. The ultimate goal at this moment is to find a system that enables one to measure the position of the suction head(s) in three coordinates. Other information is provided by measuring the draft of the ship as a function of time and speed over the bottom. For other types of dredges, other means of positioning, e.g. laser beams, are also used, the choice depending on the circumstances.

## Increasing the In Situ Density

### Natural density

24. There is a tendency for the bulk density of silt and mud, which settle in the river and the harbor basins, to increase as a function of time. Assuming a continuity in the sedimentation process, it is clear that the density will therefore gradually increase with depth, too. This stratification (which covers consistencies from water with a high concentration of suspended material to more or less consolidated material) leads to difficulties regarding the definition of depth. When an echo sounder is used, the measured depth is dependent upon the frequency of the signal for a given stratification of the bottom material. The lower frequencies show a greater depth than the higher frequencies (greater penetration). Ships can maneuver in mud with a low consistency. This means that the depth measured with a high-frequency echo sounder can give a too shallow picture of the allowable draft of ships in waterways with a muddy bottom. At present, investigations are carried out by The Netherlands Ship Model Basin to determine the maneuverability of large tankers as a function of density and viscosity of the lower layers of a channel. To achieve an optimum result of the dredging operations, it is advisable to dredge in layers that have the same density as or a higher density than the dredger can handle without additional water. Therefore, much attention is given at present to studies regarding the natural density of silt and mud. A research contract on this subject was recently awarded to the Soil Mechanics Laboratory at Delft.

### Overdepth

25. As a result of the considerations given above, it could be

advantageous to perform a certain overdepth of dredging in sections that regularly silt up with mud. Initially more work has to be done, but afterwards the maintenance dredging can probably be carried out with greater time intervals between dredgings and in a more economic way as a result of the greater density of the bottom material. At present, the overdepth in Rotterdam Harbor is kept at approximately 0.5 to 1 m, but when the investigations mentioned before are completed, this figure may be changed.

26. The subjects of natural densification and dredging overdepth are slightly controversial. During discussion of the maintenance dredging at the outer harbor of IJmuiden, it was suggested that the density of the mud to be dredged varies with the temperature of the water. No quantitative data to support this assumption were available. In many harbors the authorities are opposed to dredging overdepth as, in their opinion, it accelerates siltation. In harbors where the dredges are owned by the authorities, the problem of dredging overdepth gets less attention because the dredges work year-round anyway.

## Optimizing In-line Solids Concentration

27. For maintenance dredging the following kinds of dredging equipment are used all over Europe:

- a. Bucket dredges, barges.
- b. Barge unloading dredges.
- c. Trailing hopper dredges.
- d. Grabs.

In capital dredging, stationary dredges and cutter suction dredges are used in addition to the plant referred to above. In maintenance dredging, the dredged material (mainly mud with traces of fine sand) from bucket dredges and grabs is transported to barge unloading dredges; trailing hoppers generally transport the dredged material to the sea.

28. Since the soil is transported over water for a distance of several kilometres, a high amount of solids in the mixture is a prerequisite for an economical process. This is easily achieved when the dredged material consists of sand; in that case the hopper or barge is

filled gradually, while the effluent (with the finest fractions) flows back into the waterway. When filling with a highly concentrated sand-water mixture, the quantity of effluent per cubic metre of soil is comparatively small. If the bottom consists of mud, continued loading generally does not improve the density of the mixture in the hopper.[1] Turbidity created by the dredging process is also increased.

29. In pipeline transport, the highest possible concentration should also be achieved. The output per second is equal to $c \times Q$* where

$c$ = concentration by volume

$Q$ = discharge

The loss of head per unit distance $\Delta H$ is a function of particle concentration and discharge. The amount of energy to transport a unit quantity of soil over a unit distance is a linear function of

$$\frac{\Delta H \times Q}{c \times Q} = \frac{\Delta H}{c} \tag{1}$$

The discharge $Q$ and the concentration $c$ have, therefore, to be selected in such a way that $\Delta H/c$ is at a minimum. It appears, from tests, that when pumping a clay-water mixture as well as a sand-water mixture, there exists a minimum in the power consumption for a certain flow velocity and a certain concentration of the particles. For a fixed discharge this is indicated in Figures 6 and 7. As the efficiency of the pump decreases when the mixture density increases, the optimum density of the pump-pipeline system shifts to a value somewhat lower than found from the minimum $\Delta H/c$ indicated in Figure 7.

30. To ensure a safe operation of the pipeline and because of imperfect technology and the human factor, the density of the mixture in the pipeline will always be lower than the optimum density, while the flow velocity will be higher than the optimum velocity. In the case of the mud encountered in the Rotterdam Harbor area, the optimum mixture

---

* For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix J).

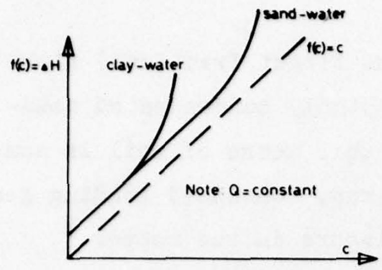



Figure 6. Head loss versus concentration

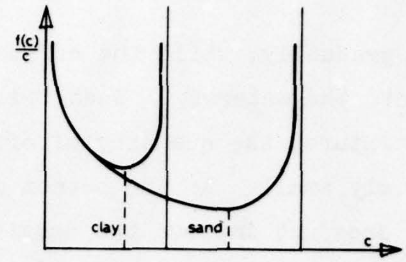



Figure 7. Energy consumption versus concentration

density is around 1200 kg/m$^3$. For fine sands, the optimum mixture density is found to be about 1600 kg/m$^3$.

## Densification During the Dredging Process

31. Densification while dredging is at this moment only applied to sand-water mixtures. Tests performed on clay-water mixtures with the aim to accelerate the fall velocity of the particles by addition of polymers did not meet with much success (see Appendix C). Centrifuges are not used to densify a clay-water mixture because of the high power consumption and mechanical difficulties in view of the quantity of mixture to be treated per second. A sand-water mixture can be dewatered in a settling basin by gravity or in a cyclone or centrifuge by centrifugal force. Every hopper or barge functions as a settling basin while being filled. It can be found from dimensional analysis that for small grains, the percentage of retention $\phi$ is as follows:

$$\phi = \frac{d\sqrt{gF\,\frac{\rho_k - \rho_w}{\rho_w}\,f(c)}}{\sqrt{Q\nu}} \qquad (2)$$

where

$d$ = grain size, m
$g$ = acceleration of gravity, m/sec$^2$
$F$ = surface area of the basin, m$^2$
$\rho_k$ = density of the grain, kg/m$^3$
$\rho_w$ = density of water, kg/m$^3$
$f(c)$ = a decreasing function of $c$ ; $f(c) = 1$ for $c = 0$
$\nu$ = dynamic viscosity, m$^2$/sec

32. As can be seen from the formula, the percentage of retention increases when $d$, $F$, and $\rho_k$ increase and $Q$ and $\nu$ decrease. The viscosity increases when many fines are present in the mixture. The influence of the concentration $c$ is not very well known. Measurements show a decrease in the fall velocity and hence a decrease in the amount of retention when the concentration increases (hindered settling).

33. Hydrocyclones have been used in an experimental way for dewatering a mixture, but they are not very extensively used in the dredging industry because of the following reasons:

a. Bad performance if the concentration of the mixture gets too high.

b. Power consumption is high.

c. Subject to abrasive action, especially if boulders are present in the mixture.

d. Sensitive to blockage because of restricted passages.

There are some advantages:

a. Dewatering is good for sand only. The wet density of the mixture from the underflow is then about 1900 kg/m$^3$.

b. The space needed is small, compared to the size of a settling basin or disposal area.

## Summary

34. Efficient and economical dredging requires proper dredges, equiped with adequate instrumentation and operated by well-trained, dedicated personnel. It requires that the dredge be able to handle the material to be dredged at the highest possible density consistent with efficient, safe operation.

35. Although not universally accepted, overdredging for maintenance purposes is considered worthwhile in many cases.

36. A balance between concentration of in-line solids and discharge should be sought that will produce a minimum power requirement. However, in practical dredging, the dredging mixture will always be somewhat lower than the optimum, while the discharge will be somewhat higher.

37. The densification of a clay-water mixture during the dredging process is not technically feasible at the present time. Densification of sands is readily achieved by gravity settling.

## PART IV: EXISTING DREDGING EQUIPMENT

38. The type of equipment used for dredging depends on the following factors:

- a. The quantities of material to be dredged.
- b. The kind of material to be dredged.
- c. The dredging depth.
- d. The distance between dredging and disposal sites.
- e. The accessibility of the dredging site.
- f. The nautical restrictions on the dredging site.

The dredges can be divided into three basic types:

- a. Mechanical, such as bucket, dipper, and grab dredges.
- b. Hydraulic, such as stationary suction and barge unloading dredges.
- c. Pneumatic, such as pneuma and airlift dredges.

Combination of the basic types (mechanical and hydraulic) occurs in the cutter suction dredge and the trailing suction hopper dredge. The dredges especially suited for maintenance dredging and for capital dredging are discussed in the following paragraphs.

### Equipment for Maintenance Dredging

39. Dredges used in Europe for maintenance dredging activities are, in general:

- a. Bucket dredges with barges that are unloaded either by dumping or by barge unloading dredges pumping ashore.
- b. Grab dredges with barges (for unloading, see above).
- c. Trailing suction hopper dredges either dumping at sea or pumping ashore.

#### Bucket dredge

40. Most bucket dredges are of the pontoon type and are not self-propelled (see Figure 8). The bucket dredge is a very popular type of dredge in Europe because of the need for an all-round dredge suited for handling many kinds of material and for a dredge that can load barges

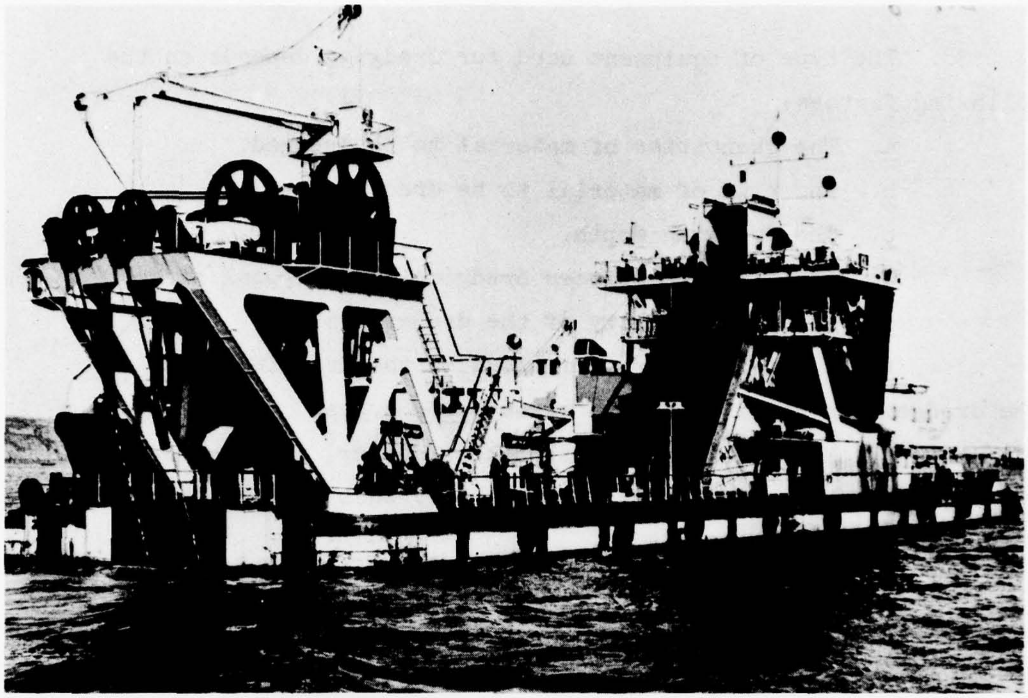


Figure 8. Bucket dredge

(since the dredged material usually must be transported over long distances to a disposal site). Disadvantages of a bucket dredge are the complicated pattern of mooring lines, the dependence on tow boats for movement, and the need to use barges for disposal. This awkward combination often forms an obstruction in the navigation routes. The various types comprise dredges with buckets varying from 0.08 to 1 $m^3$. The normal maximum dredging depth is limited to about 20 m, although a few dredges can reach a depth of 34 m.

Grab dredge

41. Most grab dredges are of the pontoon type, equipped with one grab (Figure 9). Some, however, are equipped with more than one grab. In the United Kingdom the self-propelled grab hopper dredge is very popular and generally equipped with from one to four cranes. More than any other dredge, a grab dredge is suited to work along quays and in the neighborhood of vulnerable structures.

Figure 9. Grab dredge

Barge

42. The barges can be towed or self-propelled vessels. The towed barges are normally pulled by tugboats, but there are more and more barges being built as push barges, which are transported in tow by push boats. Three types can be distinguished:

- a. Elevator barges without bottom doors.
- b. Hopper barges with bottom doors or valves.
- c. Split barges.

The split barge is getting much attention nowadays because it can easily unload difficult soils such as clay and because the control of leakage is easier than in traditional dump barges.

Barge unloading dredge

43. In Europe the barge unloading dredge (Figure 10), also called reclamation dredge, is used mainly to empty barges and to pump the

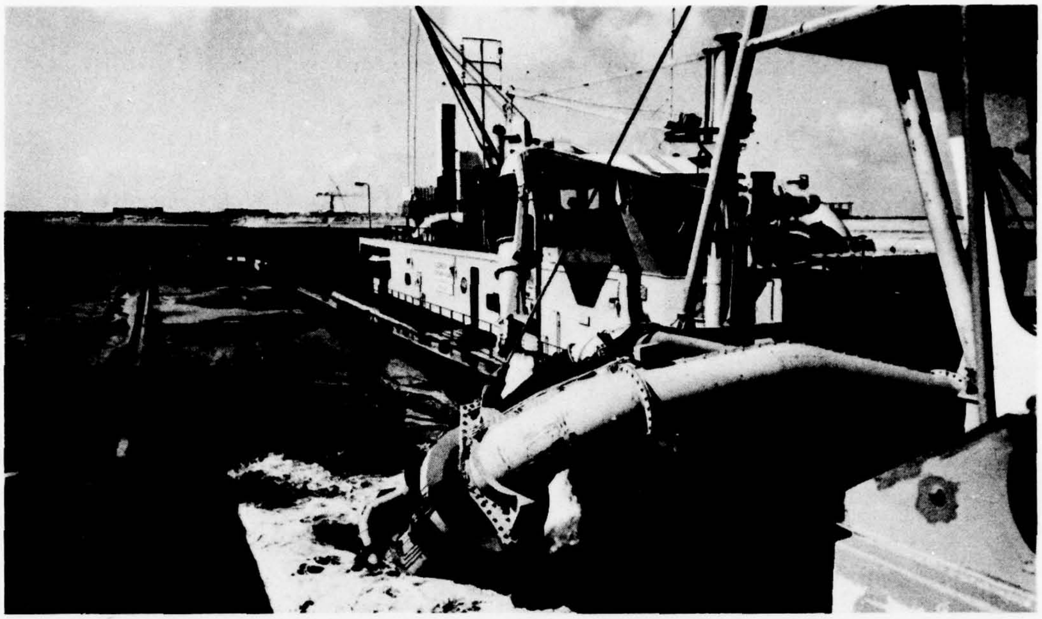


Figure 10. Barge unloading dredge

dredged material into reclamation areas. All of these dredges are equipped with water jet pumps, and the most powerful dredges can pump dredged material over distances of 3,000 m and greater. Some of these dredges are constructed in such a way that they can be converted into a stationary suction dredge.

Trailing suction hopper dredge

44. The trailing suction hopper dredge, also called draghead dredge (Figure 11), is used throughout Europe for maintenance in ports, port entrances, and port-approach channels. The advantage of this type of dredge is that it is self-propelled and forms a minimum of hindrance for shipping. The various dredges have a capacity from 800 to 18,000 metric tons. The smaller units have mostly one trailing pipe; the bigger units are all equipped with two trailing pipes. Practically all dredges are equipped with bottom doors or valves; some can also discharge by pumping their load overboard either at sea or into a disposal area.

## Equipment for Capital Dredging

45. The equipment used for maintenance dredging is also used for

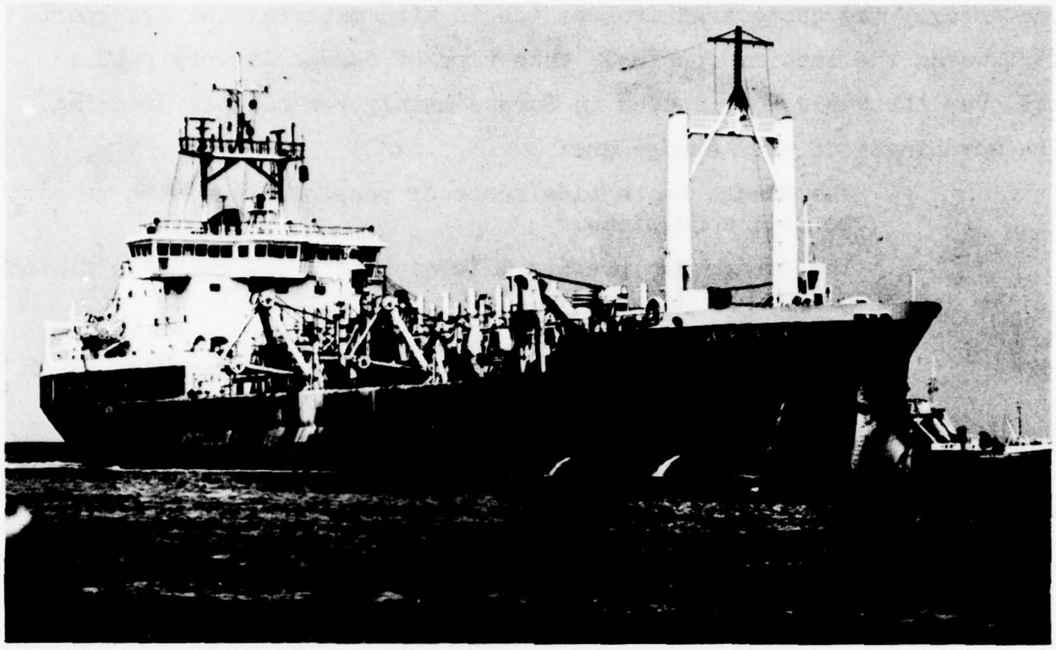


Figure 11. Trailing suction hopper dredge

capital dredging. For the latter, some other types of dredges are also used.

Stationary suction dredge

46. The stationary suction dredge is equipped with a plain suction pipe into which loose material from deep pits is sucked. The flow of the material towards the suction pipe is often increased by the application of jets. To achieve an optimum production, the dredging depth is generally very great, up to 70 m. This results in the creation of deep, isolated borrow pits. This type of dredge is capable of a larger output than any other type of comparable power, provided it works in noncohesive material. The dredged material is discharged either via a (floating) pipeline or into barges hauled alongside. If operated carefully and at a reduced output, the turbidity created by this type of dredge is in the same order of magnitude as for the Pneuma type (see Part V).

Cutter suction dredge

47. The cutter suction dredge is equipped with a rotating cutter

head at the end of the suction pipe. During the swinging motion of the dredge, the cutterhead loosens the in situ material and transports it towards the suction opening. This type of dredge is very popular all over the world and is used in Europe mainly for capital dredging. The advantages of this dredge are:

a. The dredge has a wide scope of possibilities with respect to soil conditions.

b. The dredge can prepare a level bottom and can also finish slopes.

## PART V: DEVELOPMENTS IN DREDGING EQUIPMENT

### Pneuma System

48. Some time ago Pneuma International S. A. developed a new system of dredging and transporting. The following has been taken mainly from the Pneuma International brochure. After lengthy investigations a Pneuma system has been developed which, according to the manufacturers, features the following advantages:

- a. Compactness.
- b. Simplicity of operation.
- c. Low operating costs.
- d. Minimum maintenance costs.
- e. No parts subject to wear and tear.
- f. Unrestricted dredging depth.
- g. High degree of flexibility.
- h. Production of mixture with high density.

The Pneuma dredging system can be operated both from a land base and from the traditional barge and can also be used for long distance transport of mud.

#### Operating principle of the pump

49. The standard pump consists of three steel cylinders, usually of the same section and height (Figure 12). At the bottom of each cylinder is an entrance pipe for the mixture, and at the top is a pipe for the introduction and release of compressed air and a pipe for removing the mixture (this pipe extends almost to the bottom of the cylinder). In every cylinder there is a valve above the entrance pipe that automatically closes when air is pumped into the cylinder. The mixture delivery pipe widens just above the cylinder so that it can receive a spherical nonreturn valve. When the pressure from the cylinder is decreased to let in new mixture, the delivery pipe is shut off automatically so that the mixture cannot flow back into the cylinder. The steel delivery pipes are joined by a flange sleeve to which a flexible delivery pipe is attached. The pump works as follows:

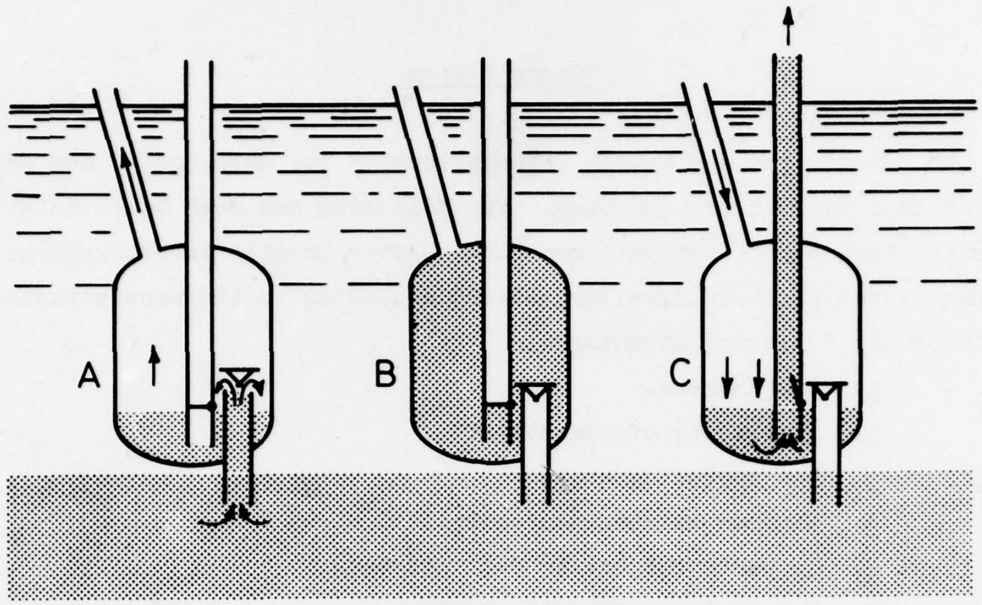



Figure 12. Working of the Pneuma system

a. Mixture flows into the cylinder, while compressed air escapes from the cylinder into the atmosphere.

b. When the cylinder is filled, the nonreturn valve in the entrance pipe closes.

c. The air is pumped into the cylinder, thus expelling the mixture from the cylinder to the delivery pipe.

With the combination of three cylinders operating in different phases of the cycle, there is constant removal of mixture. The air supply to the various cylinders is regulated by a distributor.

50. The following are areas of application of the Pneuma system:

a. Dredging layers of sediment. The pumps can take sand, gravel, cobbles, mud, silt, and clay. According to the manufacturers, attachments can be fitted in order to break up hard layers.

b. Fixed installations, where the mixture is delivered by the pump. Specific applications are booster stations and removal of industrial waste.

Dredging

51. Without attachments, the Pneuma method is suitable for mud and cohesionless material such as sand and mixtures of sand and gravel. To

start the dredging process, the pump is lowered until the three suction pipes touch the bottom. By keeping the lifting winch of the pump a little slack, the suction pipes will remain buried into the material to be dredged. The system can thereafter be pulled through the sediment. Through hydrostatic pressure, as soon as the distribution lets the compressed air out of a cylinder, it will immediately be refilled with material from the suction pipe. The greater the depth, the greater will be the difference in pressure.

52. Power specification example. As an example, the power specifications of the Pneuma pump type 300/60 are explained below:

| Component | Symbol | Specification |
|---|---|---|
| Content of cylinders | | $3 \times 2.5\ m^3$ |
| Mixture output | | $325\ m^3/hr$ |
| Delivery pipe | (d) | Ø 0.219 m |
| Dredging depth | (D) | 10 m |
| Acceleration of gravity | (g) | $9.81\ m/sec^2$ |
| Density of the mixture | (Qm) | $1400\ kg/m^3$ |
| Density of water | (Qw) | $1000\ kg/m^3$ |
| Velocity of mixture | (v) | 2.25 m/sec |
| Pumping distance | (L) | 100 m |
| Coefficient of friction | (λ) | 0.015 |
| Coefficient of loss | (f) | |

For the Pneuma pump type 300/60 head H :

$$\text{H static} + \text{H dynamic} = \frac{\frac{Qm}{Qw} + \frac{L^3}{d}\frac{v^2}{2g}\lambda\frac{Qm}{Qw}}{f\,\frac{v^2}{2g}} \qquad (3)$$

where H = 19 mwc (metres, water column). The air pressure needed $P_1$ is $2.9 \times 10^5\ N/m^2$. The net quantity of air needed is $940\ m^3/hr$ or $0.26\ m^3/sec$. The net power A is:

$$A = Q_1 P_1 \ln P_1/P_o \ N \cdot m/sec \qquad (4)$$

where

$Q_1$ = quantity of mixture per second (0.0903 $m^3$/sec)

$P_1$ = air pressure, N/$m^2$

$P_o$ = atmospheric pressure ($1 \times 10^5$ N/$m^2$)

The net power needed is 27 kw. According to the manufacturer 100 kw is used. The efficiency of the Pneuma system in this case is 27/100 × 100 or 27 percent. The net amount of air needed is 2.9 × 325 or 940 $m^3$/hr. The actual amount of air needed is, according to specifications, 6900 gallons/min or 1567 $m^3$/hr. About 40 percent of the amount of air supplied goes to compensate for losses in the system (e.g., air delivery pipes). At greater dredging depths these losses will increase and the output of the system will thus become smaller as the depth increases. These losses can be reduced by placing the air distributor on the cylinders at a great depth, so that losses from delivery pipes disappear.

53. <u>Power needed for lifting 1 $m^3$ sand at various dredging depths with the Pneuma system.</u> The mixture is brought up at a speed of 2.5 m/sec. Head (metres, water column) needed is:

$$H = \frac{Qm}{Qw} D + \frac{v^2}{2g} \frac{Qm}{Qw} f \qquad (5)$$

The values calculated for the Pneuma system are set out in Table 5.

Table 5

Power Requirement for the Pneuma System

| Dredging Depth, m | Density kg/$m^3$ | Head mwc | Air Pressure N/$m^2$ | Net Power kw hr/$m^3$ mixture | Power kw hr/$m^3$ sand |
|---|---|---|---|---|---|
| 10 | 1,400 | 14.4 | $2.5 \times 10^5$ | 0.24 | 0.52 |
| 20 | | 28.4 | $3.9 \times 10^5$ | 0.36 | 1.21 |
| 30 | | 42.4 | $5.3 \times 10^5$ | 0.60 | 2.02 |
| 40 | | 56.4 | $6.7 \times 10^5$ | 0.85 | 2.90 |
| 50 | | 70.4 | $8.1 \times 10^5$ | 1.15 | 3.82 |

It can be seen that the amount of power needed to lift 1 $m^3$ of sand rises sharply as the dredging depth increases. The efficiency of the

system is already very low (27 percent at 10 m dredging depth) and at greater depths the efficiency is even lower.

54. With a conventional suction dredge, the water pressure also assists in lifting the mixture. With the Pneuma system this water pressure is used only to fill the cylinders. Once the cylinders are filled, the delivery pipe is closed under the influence of the air being piped into the cylinders. For great depths this is a rather uneconomical system. There would seem to be possibilities for the system in shallow water because the power needed there is not too great. Another question is whether foreign bodies that get into the cylinder will come out. Oblong shapes, in particular, are unlikely to be pressed out.

55. One advantage of the system is that there are no moving mechanical parts in the pump. The three nonwearing rubber valves work automatically under the influence of pressure changes, opening and closing one to three times a minute. The air distributor unit is a very slow-moving, sturdy piece of equipment. The most vulnerable components are the flexible air hoses between the distributor and the pump.

56. No data are available on the amount of turbidity induced. It seems probable that the amount of turbidity is not much different from that caused by the draghead of a trailing hopper suction dredge or a plain suction dredge.

## Split Hopper Suction Dredge

57. Split barges have been of proven value for a long time. The advantage of a split barge is that the barge splits as a whole and no bottom doors, sliding or otherwise, are needed for the material to be dumped. Thus, there are less difficulties in discharging sticky material. Also, because the large number of bottom doors or valves are replaced by one system, it is easier to control watertightness. This is an advantage from an environmental point of view. Dumping can take place in very shallow water with split barges. Even when they go aground, they can discharge.

58. In 1972 the Bos and Kalis Dredging Company built a self-propelled split hopper dredge called the MEERVAL, suitable for inland waterways. The dredge is designed to work and maneuver on busy canals and rivers, causes little inconvenience or risk to navigation, and has all the characteristics of a split barge. Another development is the W. D. MEDWAY, a two-screw trailing split hopper suction dredge with a hopper capacity of 1500 $m^3$. This a seagoing vessel. A disadvantage of this type of equipment is its high cost of construction.

## Amphibious Equipment

### Amphibious bulldozers

59. A bulldozer was introduced in 1969 by Komatsu Ltd. in Japan. It is basically a standard bulldozer that has been adapted for working under water. It is designed as a watertight vehicle and is equipped with a snorkel for disposing of burnt gases and for piping in fresh air. The bulldozer can operate in water up to 7 m and is guided by radio. Since 1969 Komatsu has produced 11 amphibious bulldozers. The use of amphibious bulldozers can sometimes preclude the need for temporary auxiliary construction such as sheet-piling. Their chief use is in areas where the water is too shallow for floating dredges and too deep for land equipment.

60. The output of the bulldozer in Omaezaki Harbor, Japan, including breaking up hard clay with sludge, was about 120 $m^3$/hr. When the material was transported over a distance of about 100 m, the output was 39 $m^3$/hr. The water depth was about 2 m. In the Sagami River 90,000 $m^3$ of sand was removed at an average rate of 80 to 100 $m^3$/hr. Water depth was about 1 m.

### Amphibious diggers

61. In 1972 the Hitachi Construction Machinery Company in Japan produced the first amphibious hydraulic digging machine, the UA03. This machine can operate in 3 m of water and can dig down to 6 m below the water level. The machine is equipped with a snorkel. The vehicle is guided by radio and digging is completely automatic.

62. In February 1973 the bed of the River Edo near the Sehiyado, Japan, was deepened. Four trenches were dug 7 m wide, 1 m deep, and 30 to 135 m long. Digging was completely automatic and the material excavated was deposited alongside the trench. Output, including delays, was 30 $m^3$/hr.

Underwater bulldozers

63. In the last few years, two types of underwater bulldozers have been developed. The first type is called the shallow-type underwater bulldozer; it can work in up to 5 m of water. The second type is the so-called deep-type underwater bulldozer, which can work at depths of 5 to 60 m.

64. Shallow water. The three main elements of this system are:

a. Unmanned underwater bulldozer.

b. Power unit installed on a self-propelled barge.

c. Connecting bar.

Two air tanks are fitted to the bulldozer so that it can be immersed and lifted out of the water again. The movement of the bulldozer can be watched by means of a mast mounted on the bulldozer. From this mast the inclination, the depth, and the direction of operation of the bulldozer can be determined. The air and oil delivery pipes are attached to the connecting bar of the barge and the bulldozer.

65. Deep water. This type of bulldozer system can work at depths of 5 to 60 m. The system consists of a power unit mounted on a pontoon, an underwater bulldozer, and connecting cables. The underwater bulldozer is driven by hydrostatic transmission. Two air tanks are mounted on the bulldozer. Whenever these tanks are filled, the bulldozer rises to the surface. The ground force can be adjusted from 0 to 24,000 kg by these tanks. The control system consists of a complete set of instruments enabling constant monitoring of the behavior of the bulldozer, its position, the inclination at which it is working, and the direction. There are two types of underwater bulldozers on the market (up to now only in Japan, since these machines have not been given export licenses), and they are made by Hitachi and Komatsu. Various new problems have arisen:

a. Visibility is very bad at 60 m depth. Mud and sediment are stirred up, which further worsens visibility. The position, angle, and direction of the bulldozer are very difficult to determine.

b. The system is bulky and transport is difficult.

c. The hydrostatic pressure causes problems with sealing.

66. Output results. The underwater bulldozer has already been put to various uses in Japan and various tests carried out. In Omaezaki Harbor it operated in hard clay for 90 days at depths of between 5 and 10 m. When this material was loosened and piled up, the output averaged 80 $m^3$/hr. The heaps of clay were then lifted to the surface by a grab.

Underwater dredging vehicles

67. Model by Komatsu and Sumitomo, Japan. This vehicle is an underwater suction dredge that creeps along the bottom at a maximum depth of 7 m. The vehicle is operated by one man in a cabin that can move up and down a mast in order to keep its position about 1.5 m above the water surface. The dredge is said to be able to work safely and efficiently in rough seas (waves of up to 1.5 m). It can be used for various purposes, such as dredging harbors, dredging trenches to lay oil pipelines in shallow waters, nourishment of beaches, dredging close to quays, etc. This equipment permits precision dredging because it can travel along the bottom. The suction vehicle can be taken apart and transported overland.

68. Model by Ocean Science and Engineering, Inc., U. S. The most important components of this dredge are a ladder, cutter, cutter engine, suction pipe, operator's compartment, engine room, undercarriage, and spud poles. The ladder consists of a framework construction, a cutter head, and a cutter motor. The ladder, which can be moved up and down with hydraulic cylinders, supports the suction pipe between the cutter head and the dredging pump. The cutter drive consists of a hydraulic engine and a transmission on the front of the ladder. The body of the vehicle consists of two cylindrical steel chambers connnected by a pipe with a length of 2.40 m. The dredge is accessible via a tower to a depth of 15 m. It can be equipped with a gate for entry by divers or for escape purposes. The undercarriage is a Caterpillar D-9. The

spuds are used to adjust the inclination of the vehicle or lift it when repairs are necessary. The spuds can lift the machine 90 cm off the ground. This equipment has worked in Fort Pierce, Florida, where it was used to improve a 2-m-long eroded beach. The sand was dredged 1 m off the coast and pumped to the beach through a 30-cm steel pipe. The first prototype (built around 1970) has been rebuilt several times since then, with continuously improving results.

69. Underwater dredge excavator. This new system was designed for work in the Bay of Tokyo, where, for a variety of reasons, conventional methods cannot be used. The movements of the apparatus are controlled from a floating platform. The dredge excavator unit consists of a cutter located in front of the suction pipe of the sand pump. This combination can handle anything from soft mud to dense sand. The cutter, pump, and hydraulic power unit are mounted on a skid to which two air tanks are attached to regulate the ground pressure and bring the machine to the surface. Hydraulic cylinders are mounted on the skid for adjusting the angle of the cutter. The depth of the cutter is continuously monitored with a sonar device at the front of the machine. The mixture dredged is pumped to a barge. The dredge excavator is pulled along by the auxiliary ship. It is not clear how the depth of this device can be controlled. Tests results in the Bay of Tokyo showed that the output of a unit was 60 $m^3$/hr. The cutter speed was 26 rpm and the speed to travel varied from 2 to 4.5 m/min. The solid material content of the dredged mixture was between 26 and 30 percent.

## Minidredging Equipment

70. A series of small dredging units have been added to the range by IHC Holland. This equipment is chiefly developed by Konijn Machinebouw in Hoorn. The amphibious character of some of the IHC amphidredges enables them to be transported to the most remote areas. The IHC series consists of the equipment described in the following paragraphs.

### Hydraulic scoop or grab dredge (H series)

71. The amphidredge H-series equipment is amphibious (Figure 13).


Figure 13. Amphidredge series H

Each machine can move itself from land into water and vice versa. This equipment can work on flat land, on hilly terrain, in swamps, and in water. The models equiped with four legs can move over steep hills and steep rivers or canal banks to reach the dredging or excavating site. The models equipped with three legs are somewhat restricted in this respect. Each machine consists of:

- a. A main pontoon.
- b. Three or four movable legs, hydraulically operated, permitting displacement of the vehicle by crawling (like a turtle). The equipment stands firmly on the legs during excavating/dredging, which is why these machines have such a remarkably high dredging capacity in relation to their size.
- c. A hydraulic excavator with backhoe, clamshell grab, or moving bucket.

The principal characteristics of the machines are summarized in Table 6.

Table 6

Minidredges, Series H

| Characteristic | Dredge Type H150 | H400-3 | H400-4 |
|---|---|---|---|
| Number of legs | 3 | 3 | 4 |
| Max. reach excavator, m | 5.00 | 6.70 | 6.70 |
| Max. dredging depth (with backhoe) | 2.40 | 4.50 | 4.50 |
| Engine, hp | 37.5 | 74 hp | 88 hp |
| Weight, kg | 5,500 | 12,000 | 14,000 |
| Content of standard backhoe, ℓ | 150 | 400 | 400 |
| Min. canal width, m | 1.60 | 2.60 | 2.60 |
| Min. waterdepth for navigating, m | 0.70 | 1.05 | 1.05 |
| Min. waterdepth for operating, m | nil | nil | nil |

Mechanical grab dredge (M series)

72. Each of the two M-series machines consists of:

a. A self-powered mobile grab dredge crane that can operate from both land and water when installed in the floating pontoon system. The crane is also used to place the pontoon system and the auxiliary equipment in the water and back on the trucks after completing the job.

b. A floating pontoon system to carry the grab dredge crane when operating from the water.

The principal characteristics of these machines are summarized in Table 7.

Milling cutter dredge (S series)

73. The S-series machines all employ a milling cutter suction system developed in Holland especially for the maintenance dredging of silt and organic sedimentation. This system uses the pumping principle rather than the excavating principle. The milling cutter suction system consists of:

a. A milling cutter scoop for funneling the silt or other

Table 7

Minidredges, Series M

| Characteristic | Dredge Type M350 | M500 |
|---|---|---|
| Length of standard boom | 9.00 | 11.00 |
| Engine, hp | 31.5 | 31.5 |
| Weight, kg | 13.700 | 14,000 |
| Content of standard grab, ℓ | 350 | 500 |
| Min. waterdepth required, m | 0.50 | 0.50 |
| Min. canal width without side pontoons, m | 2.60 | 2.80 |

loose deposits towards the suction opening, thereby enhancing the solids/water ratio.

b. A milling cutter device for cutting vegetation, branches (small), large hard soil lumps, etc., and at the same time mixing all these components into an evenly distributed mixture, thereby enhancing the performance of the pump.

c. A special pump with an impeller able to handle relatively large pieces of debris such as food cans, shoes, bricks. etc., thereby minimizing downtime due to clogging of the pump.

74. The Amphidredges S170 and S200 can also be outfitted with three or four legs so that they can turtle walk on their own power from the transport vehicle over land into the water and, when onsite, around small bridges and other obstacles. The principal characteristics of the S-series machines are summarized in Table 8.

## Airlift Dredge

75. The airlift principle, discovered in 1797 by C. J. Loscher, consists of introducing compressed air into the bottom of a vertical pipe immersed in water. The expanding air rises, creating currents that carry up any solid material as well as water. The pressure required for the air depends on the operating depth of the transport pipe. The

Table 8

Minidredges, Series S

| Characteristic | Dredge Type S170 | S200 |
|---|---|---|
| Max. dredging depth-forward, m | 3.20 | 3.50 |
| Max. dredging depth-backward, m | 5.00 | 5.35 |
| Production, $m^3$/hr | 50 to 80 | 100 to 140 |
| Diameter suction pipe, m | 170 | 200 |
| Engine, hp | 110 | 165 |

greater the operating depth, the greater the air pressure must be. The greater this pressure, the greater is the expansion and therefore the transporting capacity. Since the air pressure depends on the operating depth, a minimum operating depth is needed for economical dredging. This is roughly between 7 and 10 m.

76. In air pressure suction dredges, the compressed air is delivered in a special transport head, which, at the same time loosens the soil. The transport head is either rotated or vibrated, depending on the conditions. The air pressure is built up by compressors whose dimensions and capacities vary according to the solid material capacity needed, the composition of the material, and the operating depth. The ratio of solid/water averages 1:3 in compressed air dredging. Transporting is continuous. The sand-water mixture runs into a tank and can be taken directly from the tank to a dewatering unit or to a barge.

## PART VI: CONCEPTS FOR DISPOSAL

77. The following points are the basis of any discussion of disposal of dredged material. First, the dredged material must be disposed of. This is clear if one realizes that after a long and democratically controlled process of judging advantages and disadvantages it has been decided to carry out a project that involves the transport and storage elsewhere of sand and/or clay. The same applies to disposal of material from maintenance dredging, which cannot be interrupted without considerable harm to the economy, possibly resulting in large-scale unemployment, or without doing harm to the water management (and consequently the environment) in certain areas.

78. Second, dredged material is either polluted or unpolluted. Sand and clay from capital dredging are generally unpolluted; however, silt from maintenance dredging may often be polluted to some degree.

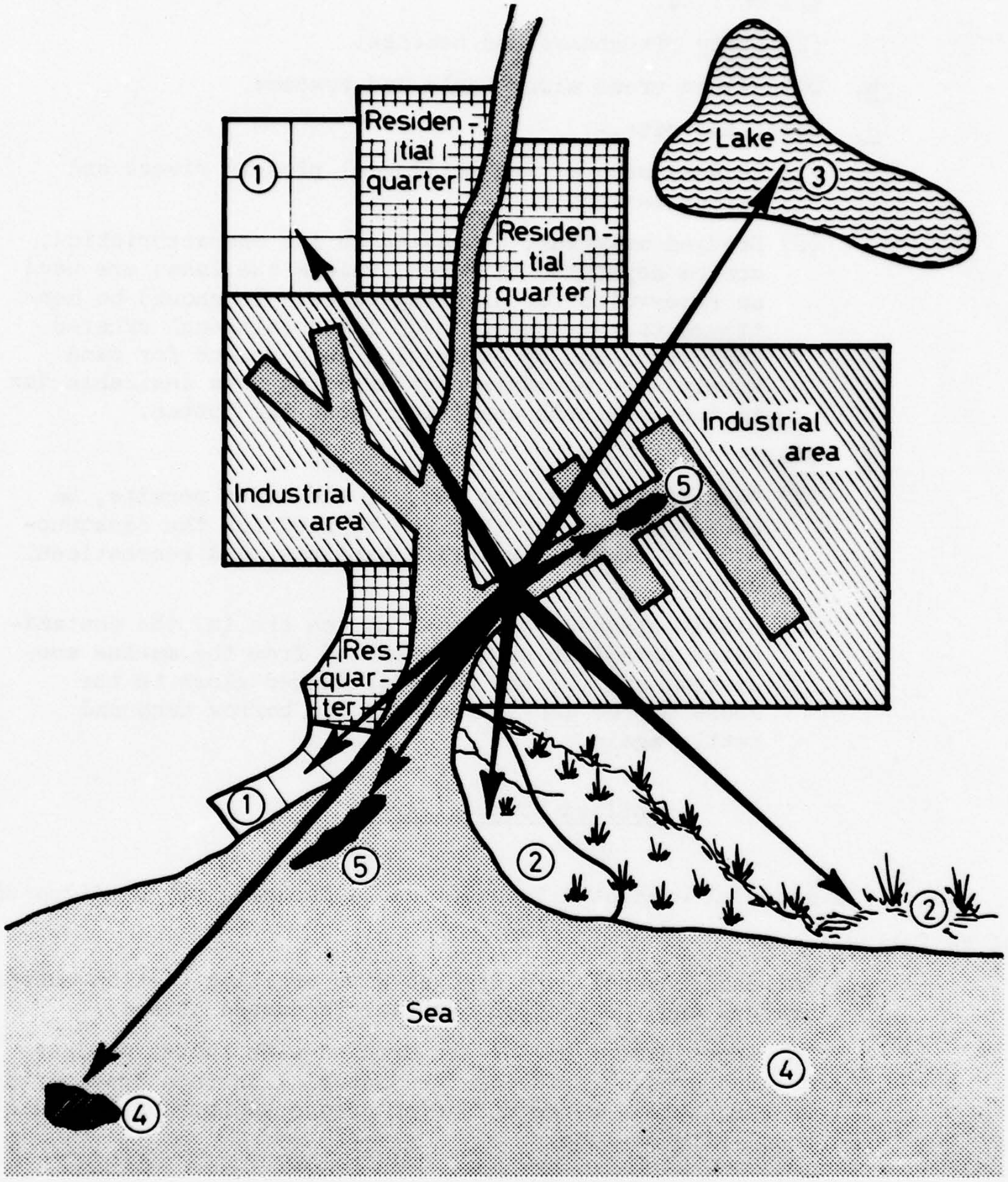
79. Finally, the disposal of dredged material should be accomplished at the minimum social cost. This means that consideration must be given to direct cost as well as advantages or disadvantages for landscape, environment, or society. This can be worked out into more concrete recommendations:

- a. The disposal site must be located in the vicinity of the dredging area in view of transport costs.
- b. The dredged material should not be moved back into the estuarine system by the prevailing natural conditions.
- c. The disposal must be acceptable as to the environmental aspects (landscape, ecology).
- d. The disposal must not (or only temporarily) cause trouble to the surroundings and, if possible, it should ultimately serve a useful purpose (e.g., soil improvement, recreation, reclamation for industrial or residential settlements).

### Inventory of Alternatives

80. The possible locations for disposal of dredged material are schematically presented in Figure 14. They are:

- a. Confined areas.




1 Confined areas on land or along riverbanks and beaches.
2 Unconfined areas.
3 Lakes.
4 Sea.
5 Pits in rivers or harbor basins.

Figure 14. Disposal of dredged material

(1) On land.

(2) Along riverbanks and beaches.

b. Unconfined areas along banks and beaches.

c. Lakes and pits.

(1) In deep natural and artificial pits in rivers and harbor basins.

(2) Dredged material, depending on its characteristics, can be deposited in lakes, unless the lakes are used as reservoirs for drinking water. It should be mentioned that extremely deep lakes (although created some years ago by excavation as a source for sand supply) are nowadays considered as less desirable due to the anaerobic conditions near the bottom.

d. Sea.

(1) Sand, silt, and clay can, if the depth permits, be dumped at sea, or they can be used for the construction of beaches, wildlife habitats, and recreational areas.

(2) Disadvantages of disposal at sea are (a) the contaminated materials are not removed from the marine ecosystem, and (b) the material dumped close to the shore may be carried back to the borrow area and settle again.

## Confined Disposal Areas

81. The material excavated in maintenance dredging may be disposed of as follows:

a. Entrance channels are dredged with trailing suction hopper dredges and the dredged material is dumped at sea.

b. The inner harbor basins are dredged with bucket dredges or grab dredges. The dredged material is then transported in barges to a barge unloading dredge and pumped to a disposal site on land.

The following paragraphs shall discuss the reclamation of dredged material in confined areas (b above).

82. Dikes are constructed prior to commencement of the reclamation. Due attention is paid to the soil mechanics aspects of the dike construction, and stability is checked regularly during the reclamation process. Excess water entering into the disposal area along with the dredged

material is discharged through an outlet system. Depending on the quality of the effluent (salinity), special measures may have to be taken to avoid intrusion of brackish water into a freshwater system. After the filling of a fresh layer and the drainage of free water, measures are taken for rapid dewatering of the dredged material. Gradually the ripening process is initiated wherein the mud is converted into ripened soil, which is accessible and useful for various purposes. The dikes are then raised by making use of the reclaimed soil and another layer is spouted. This process repeated several times brings the site to grade.

83. The number of layers depends on several factors such as the intended height of the disposal area, the quantity of dredged material to be stored, the time until the land is to be used for its ultimate purpose, the grain size of the dredged material, etc.

Size and layout of the disposal area

84. Size. The disposal area is divided into a number of smaller units. The size of each unit is to be kept within certain (upper and lower) limits. The composition of the dredged material (especially the percentage of fines) and the quantity of material to be stored in a certain period play an important role in this respect.

85. For a given amount of dredged material to be stored during a given period, small units have the following disadvantages:

a. Settlement of the finer particles is more difficult due to the short stay of the mixture within the unit.

b. Higher construction costs per cubic metre of stored material (more and/or higher embankments).

The application of larger sized units means:

a. Longer period of filling in each unit and, consequently, a longer cycle time.

b. More extensive damage in case of bund failures.

c. Problems with the planning of dredging operations and less flexibility in switching over to other disposal units in the event that the reclamation process is delayed as a result of soil mechanics or other problems during the construction of the disposal area or during the filling operation.

86. The average weekly output of dredged material from maintenance dredging in Rotterdam is 60,000 $m^3$ not including the water added by the barge unloading dredge for dilution purposes. The optimum size of disposal area units is considered to be between 200,000 and 500,000 $m^2$. Smaller units are also used and, as long as they are combined in a complex together with larger units, they do not present a serious disadvantage. In such a case it is possible, by simply opening and/or closing valves, to extend the filling of such a small unit over a longer period by alternatively filling a nearby larger unit.

87. The total area X in square metres necessary for disposal of the dredged material can be calculated as follows:

$$X = \frac{Y}{Z} \times T \qquad (6)$$

where

Y = dredged quantity, $m^3$/year

Z = thickness of a discharged layer, m

T = cycle time of the disposal area units (discharge, dewatering, and heightening the embankments), years

88. Layout. Considering the geography and the optimum size of units within the disposal area, the available area is divided into one or more units. If there is more than one unit, a discharge channel with a settling basin is created.

89. The excess water is discharged through the canal into a basin; after settlement of the fine particles, the water is allowed to flow into a second basin from where it is discharged to open water by pumping or by gravity flow. In Rotterdam the water is generally pumped back into the river. A schematic design of the typical layout of a disposal area is presented in Figure 15.

90. Attention is further drawn to the ditch around the disposal area, in which seepage water is collected. In the past, a different disposal area design also was used, i.e., one without a central discharge channel. In this case, excess water was discharged across the other units of the area towards the pumping station. This system was

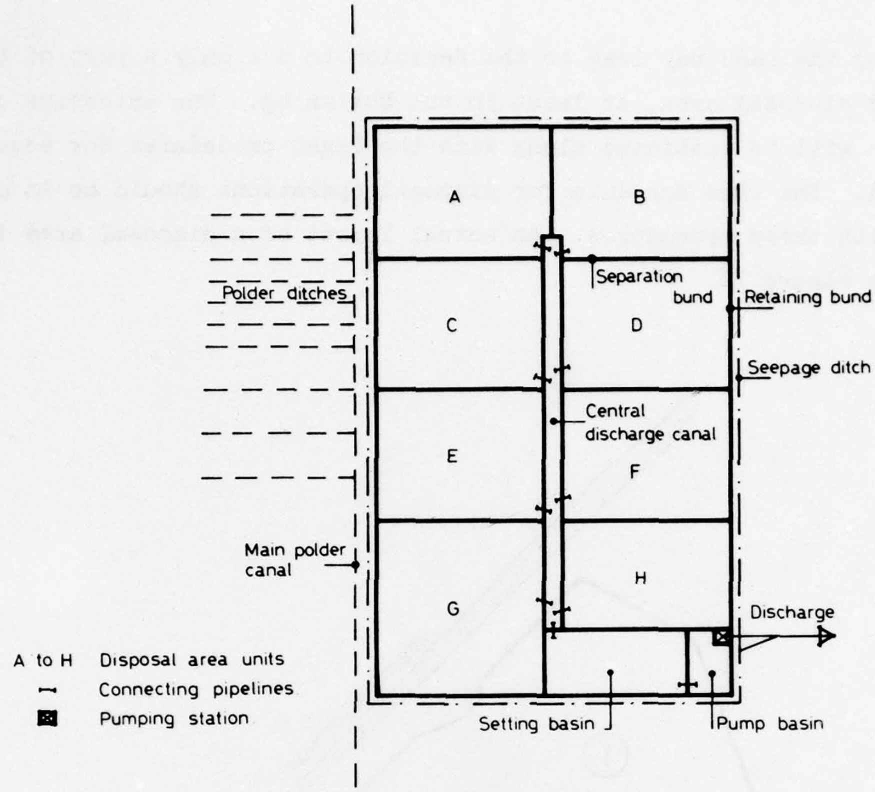



Figure 15. Typical layout of a disposal area

abandoned because it meant that the units were flooded during a long period, a serious disadvantage for dewatering and ripening.

91. The boundaries and shapes of these disposal areas were, for a large part, determined by the following factors:

- a. The existing infrastructure that has to be maintained (canals, roads, railroads, pipelines, cables, etc.).
- b. Existing buildings that cannot be removed.
- c. Hydrological and hydrographical conditions (dikes, etc.).

Usually a change in these factors is too costly to be considered. It is more attractive, then, to construct the embankments of the disposal area at such distance from existing objects that no alteration is caused. For this purpose extensive soil mechanics calculations are required.

92. Apart from physical factors, legal considerations may also influence the boundaries of the disposal area. For instance, the ownership of the land to be used may play a role, and difficulties in

acquiring the land may lead to the decision to use only a part of the proposed disposal area, at least in the beginning. The extension of the area will be initiated along with the legal procedures for acquiring the land. The time schedule for disposal operations should be in accordance with these procedures. An actual layout of a disposal area is shown in Figure 16.

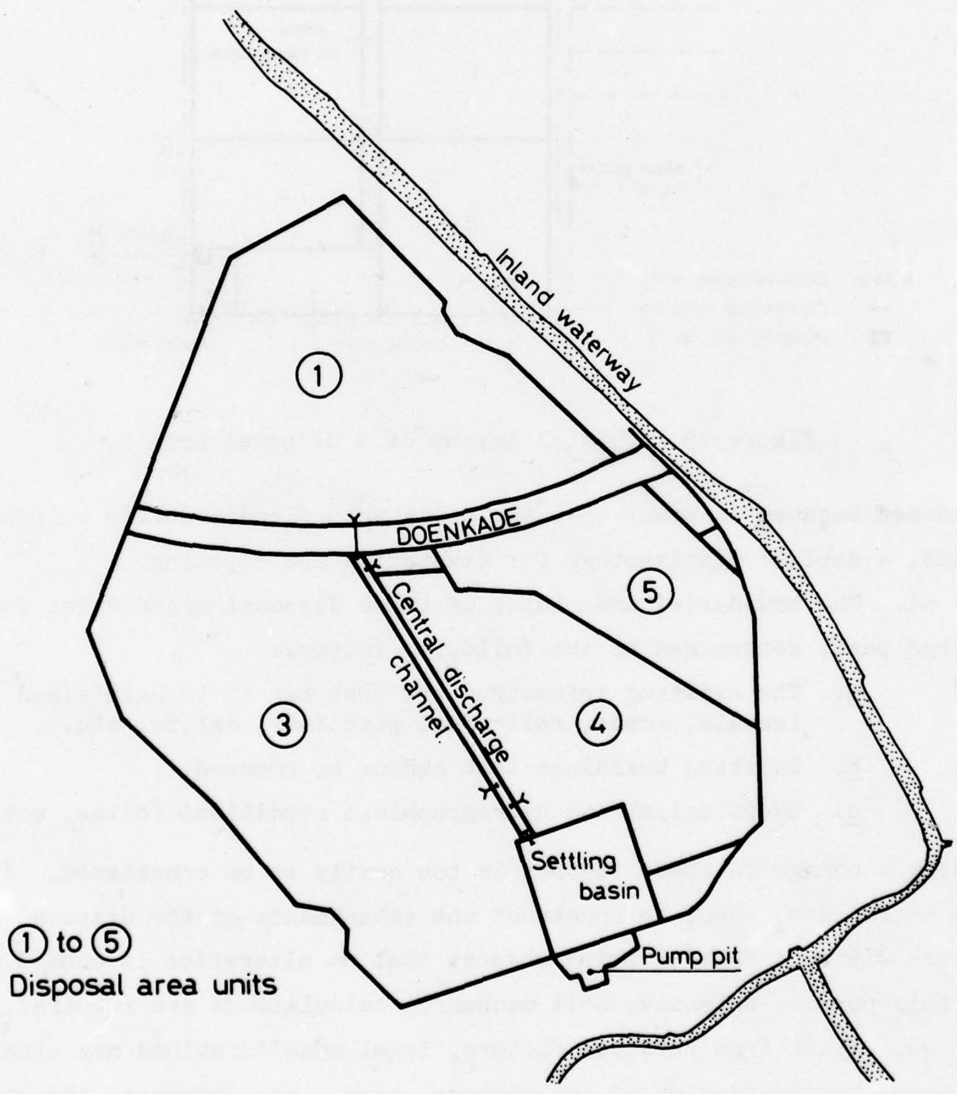



Figure 16. Actual layout of disposal area

Retaining embankments

93. Requirements. The retaining embankments that surround the units of a disposal area have to meet certain requirements in respect to soil stability, crest level, crest width, and cost.

94. The cross section of the bunds should be sufficient to ensure against sliding of either the embankment proper or the subsoil. The embankment should not subside and thus cause nearby upheavals. Finally, the permeability should be so low that no loss of stability occurs due to erosion.

95. The crest level of the embankment should be high enough above the final planned elevation of the dredged material so that both water and dredged material can be stored with enough freeboard to allow for local irregularities and possible consequences of bad weather conditions. The width of the crest should allow the passage of trucks and cranes even when a delivery pipeline has been laid along the crest.

96. The level of the embankments is generally 0.5 m higher than the level of the layer to be discharged. In Rotterdam, the optimum thickness of consecutive layers is 1 to 1.5 m. This is a compromise between the time required for dewatering and the cost of the disposal operation. Thus, the embankments reach a height of 1.5 to 2 m. The width of the crest is generally 3.0 m. The slopes of the bunds and the width of the berms between the bund and the borrow pit are determined after careful soil mechanics considerations. The outer slopes are generally 1:3 and the inner slopes 1:1.5. The width of the berms varies between 5 and 20 m or even greater. The embankments between the units may have the slopes of 1:1.5 on both sides if the fill rate on both sides is close to equal.

97. From a soil mechanics point of view, the seepage ditches around the disposal areas diminish the stability of the embankments. Nevertheless, these ditches cannot be omitted due to conditions imposed by the authorities responsible for the water management. To safeguard the quality of the surrounding surface water, the level in the seepage ditches must be maintained below that of the surface water.

98. Also, if the soil conditions are poor, it usually is feasible

to construct embankments than can resist the pressure of more than one layer of dredged material. In this case, an adapted working method should be applied. In Rotterdam's Oost-Abtpolder, for example, a layer of sand was supplied. Underneath this sand layer, vertical sand piles were installed to drain the groundwater. Thereafter the embankment was constructed and covered with a layer of clay. The described method requires higher initial costs, which are only partly compensated by savings in subsequent phases. Also, the time required for consolidation of the subsoil is considerably longer. Again, the time lost in the initial phase is not regained later on. The intervals between two discharge operations, which are required anyhow for dewatering and ripening, give ample time to raise the embankments. Therefore, it largely depends on the local conditions whether this method of embankment construction is justified.

99. Raising the embankment. When a unit of a disposal area has to be prepared to receive the next layer of dredged material, the ripened soil from the previous layer is used for raising the embankments. This can only be done after the dredged material has ripened to such an extent that it can be used as soil. The heightening of the embankment is achieved in one or more layers, depending on the consistency of the dredged material. The ripening process itself is accelerated by the digging.

100. Figure 17 shows a typical cross section of an embankment constructed in several phases. In this sketch, it has been assumed that it is acceptable from a soil mechanics point of view to construct a continuous outer slope of 1:3.

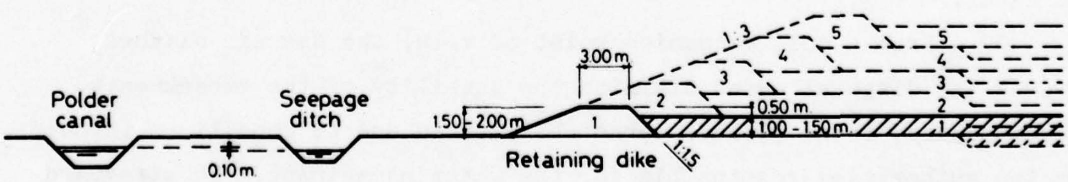



Figure 17. Typical cross section of disposal area

101. If a slope of 1:3 is too steep for the stability of the embankment, one possible solution is the construction of the next embankment at the inner side of the previous one(s) (Figure 18). The disadvantages are the greater quantity of soil required, a more complicated construction method, and a loss of storage area. An insight into the soil mechanics stability calculations for dikes in The Netherlands can be obtained from Tiederman and Reischman.[2]

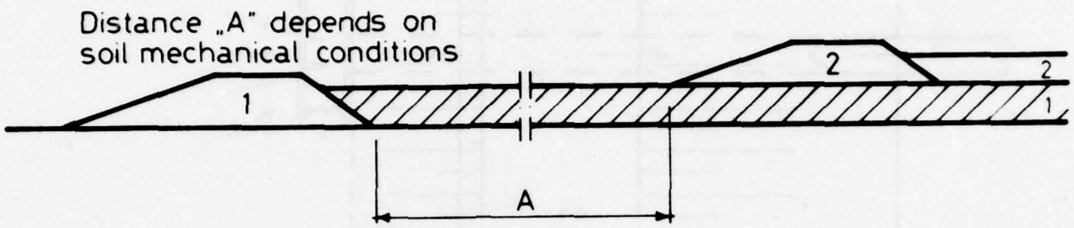



Figure 18. Alternative cross section of disposal area

Discharge of effluent

102. The effluent water from the disposal area is discharged via evacuation boxes (drop inlet sluice). These boxes consist of a riser inside the disposal area and are connected by a number of steel pipes through the bund of the area. Figure 19 shows an example of an evacuation box as commonly used in Rotterdam. The base is a rectangle; the bottom and the two shorter (side) walls are fixed. The side walls should be at least 0.5 to 1.0 m above the filling level of the disposal area. The lower side of the back wall is connected to at least one discharge pipe. The bottom, the back wall, and the two side walls can be made of wood or steel. The front wall consists of loose horizontal planks; the water level inside the disposal area can be controlled by changing the number of planks. The effluent water flows over the uppermost plank into the riser and is discharged via the steel pipe, generally into the central discharge channel. This type of evacuation box is also used for the connection between the discharge channel and the settling basin and pump basin. The silt particles that are present in

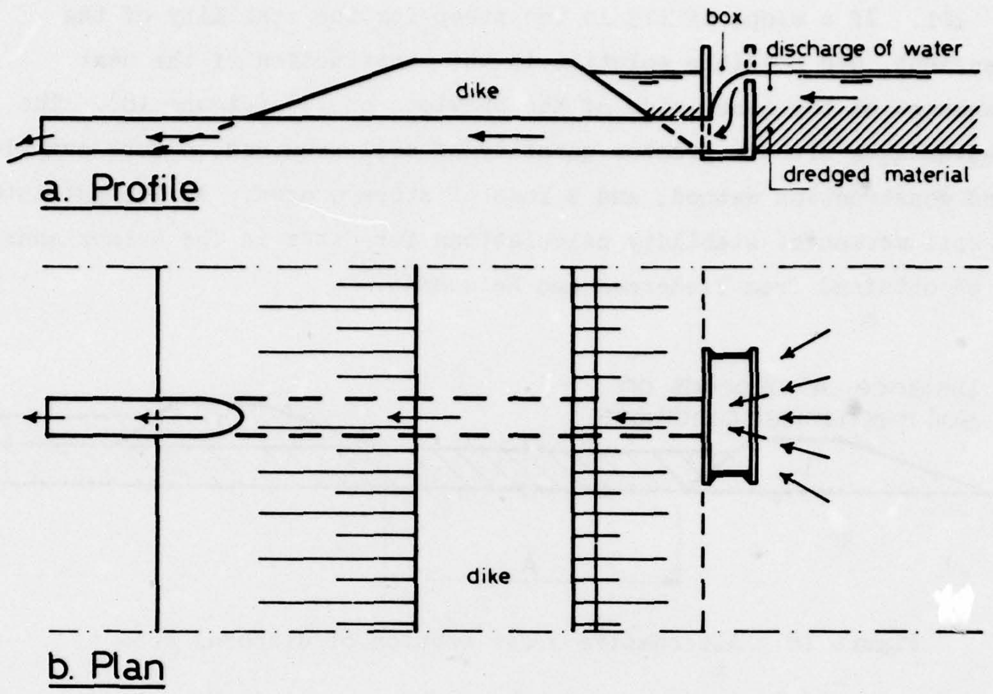



Figure 19. Box outlet sluice

the discharged water should be deposited in the settling basin. In this way, the effluent water contains only a negligible percentage of suspended matter. This is generally a requirement imposed by the authorities responsible for the quality of the surface water.

103. The effluent water may contain a high concentration of phosphates. To reduce the effect on the growth of algae, ferrosulphite is sometimes added to the effluent water.

Disposal operations

104. The actual disposal of dredged material starts with the first filling after the receiving disposal unit has been completed and the embankment and the discharge system have been checked. After approximately 0.5 m of dredged material has been brought into the disposal unit, some dredged material (mud) is spread over the inner slope of the embankments to reduce the permeability of the embankments, so that the risk of softening is eliminated (cracks in the bunds are also repaired in this way). Until recently it was done by hand; nowadays it is done with a small floating crane.

105. The delivery pipeline is constructed along at least two sides of the disposal unit. During the filling of the unit, the end of the delivery pipeline is moved several times. In this way a more homogeneous fill is achieved. The coarsest particles of the mixture will settle close to the orifice, whereas the finer particles are deposited at greater distances. The number of times that the orifice is moved depends on the size of the disposal unit and on the composition of the dredged material. For the discharge of a second layer, it is often advantageous to move the evacuation box to another part of the disposal unit, preferably to the opposite side where the delivery pipe was previously located. By this procedure, the distribution of fine and coarse particles will be the reverse of the distribution of the previous layer and it leads to homogeneous soil consistency. In this respect it must be mentioned that the subsidence of the reclaimed soil increases with the amount of fines in the mixture. A homogeneous distribution of fine and coarse material over the disposal unit thus eventually leads to a uniform level of the disposal area.

106. During the discharges attention should also be paid to erosion of the bottom by the force of the jet from the delivery pipeline. This is mainly a point of concern for the discharge of the first layer in a new disposal area where peat or soft clay is present near the surface and it is possible that lumps of peat or clay will be eroded and the dredged material will penetrate layers far below the original ground level. In a number of cases this has caused undermining of the embankment of the disposal area. This erosion can be prevented either by the application of a special type of orifice that is designed to dissipate energy (perforated pipe or special plate) or by the construction of a revetment that prevents the scouring (reed mats covered with rubble). Further, it can be mentioned that it is common practice in Rotterdam to cut the grass on and along the bunds prior to the spouting in order to facilitate inspection.

Dewatering

107. The dredged material in disposal areas has the character of unripened soil, which is characterized by the following properties:

a. Saturation with water, absence of air.

b. Soft consistency, low bearing capacity.

c. Low density, high porosity.

d. Very low permeability to water.

For such material to become suitable for use (planting, cultivating, road building, etc.), it must go through a ripening process. The ripening process consists of removing the water, which causes the distance between the grains to diminish and the overall volume to decrease (subsidence). Therefore, due to the denser structure, the bearing capacity increases. Apart from vertical subsidence, the volume reduction also leads to cracking. The higher the clay content, the more marked will be the shrinkage and the more intensive the cracking. A discussion of the dehydration of clay minerals is given in Appendix D. As a result of cracking, there is a sharp rise in permeability (from a tenth of a millimetre to several metres per day). Dewatering can be considerably boosted by this. Cracking enables air to reach the sediment. The color changes from dark blue-grey to light brown-grey (oxidation of ferric sulphide compounds). Soil life begins, weeds begin to grow, and animal and root passageways appear. In a word, the slushy mud in time becomes solid soil, which can hardly be distinguished from natural sediments. With advancing ripening, salts are leached, encouraging root growth.

108. If no special action is taken, ripening is a very long, drawn out process (many years). The water is removed mainly by evaporation. Artificial means, however, can also be used (osmosis, electro-osmosis, vacuum drainage, vertical sand drains), although such measures are very costly and are less suitable for large expanses such as dredged material disposal areas. An exception is the reclamation method used in Hamburg where dewatering is considerably boosted by alternately spouting layers of mud and sand (Figure 20). The successful experience with this system is confirmed by recent experiences in Rotterdam (Europoort), where a rapid dewatering was achieved by reclaiming mud over a sandy subsoil. Further, in Rotterdam, a horizontal pipe-drainage system was introduced after trials in 1972 and 1973. This system is, however, not yet

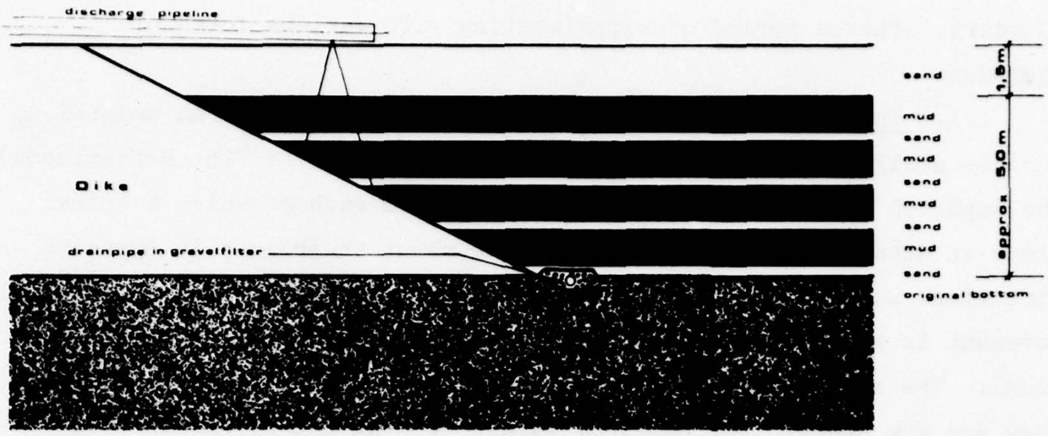



Figure 20. Layered disposal area (Hamburg)

economically feasible in all circumstances. There is extensive literature on this type drainage.[3]

109. Natural evaporation can be strongly encouraged by removing the surface water as quickly as possible. The best way of doing this is by furrowing. But technical execution only becomes possible through the introduction of two types of devices: the Amphirol (for the first stages of furrowing) and the disc wheel (for later stages). The function of furrows is essentially as follows. Furrowing increases the surface area of the mud, increasing evaporation. So long as no cracking occurs, rainwater can collect in the furrows (catchment) and run off (drainage) without the surface of the mud becoming waterlogged. The effective ripening time per year is thus considerably lengthened. It is estimated that ripening takes place only during 3 months in an unfurrowed disposal site in The Netherlands. By furrowing, the ripening time can be extended up to about 10 months per year.

110. As stated, for the purposes of storing dredged material and for rapid use of the reclamation area, it is important to dewater dredged material quickly. Three systems are used:

- a. Furrowing with the Amphirol.
- b. Furrowing with disc wheels.
- c. Horizontal drainage.

The Amphirol and disc wheels have been used in Rotterdam for the last

10 years, after a period of experimenting with various forms of equipment.

111. The Amphirol. The Amphirol (see Figure 21) is an amphibious vehicle designed and built by J. J. de Bakker in Hulst (The Netherlands). The Amphirol is supported by two cylinders, to each of which a spiral blade is attached. The cylinders rotate about their axes in opposite directions so that the vehicle can travel forwards or backwards (lateral movement is also possible by revolving the cylinders in the same direction). The cylinders are about 5 m long with a diameter of about 1 m; they are 2 m apart. The Amphirol weighs 4000 kg and is driven by a 115-hp engine.

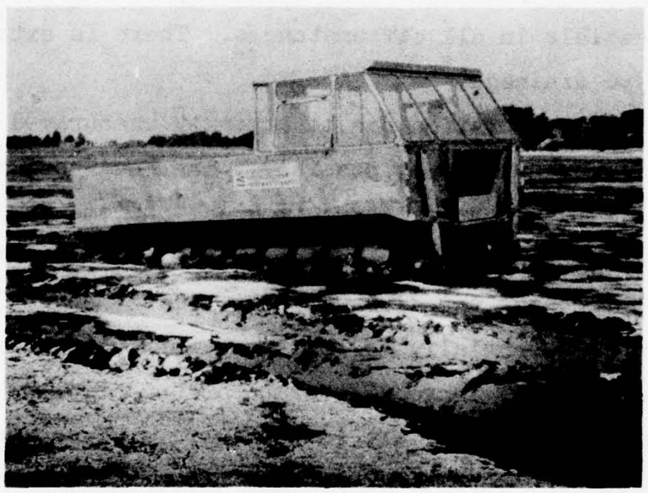
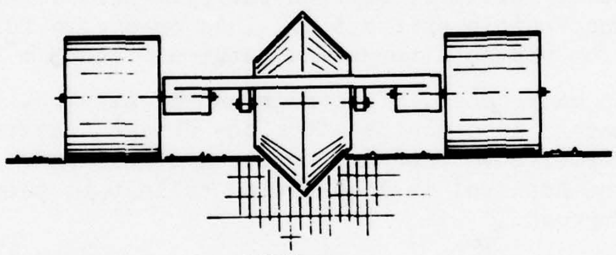


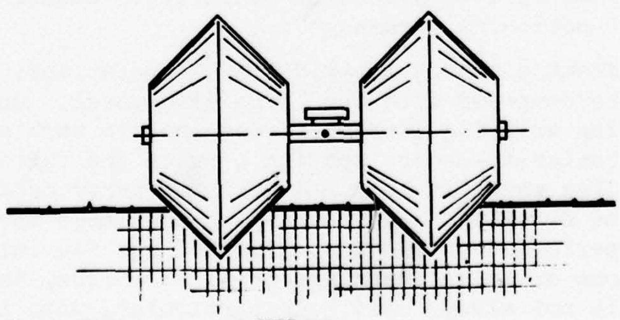
Figure 21. Amphirol

112. Disc wheels. Disc wheels of various sizes are used (see Figures 22 and 23). Twin wheels with a maximum diameter of about 2.50 m are used. These wheels are towed behind the Amphirol or they may be pulled to and fro by a cable between two tractors with winches operating from the bund. A single disc wheel about 3.50 m in height (maximum diameter) can also be used. On both sides of the axis of this wheel, there are cylindrical wheels (diameter 2.30 m and width 1.80 m) to prevent the single disc overturning. This large wheel, designed and used by Konijn Baggerwerken B.V., is also moved across the ground by cable. The whole construction, wheels and large disc, is about 9 m wide. All

Figure 22. Twin disc wheel



| | |
|---|---|
| Discus wheel | ø 3500 mm. |
| Stabilising wheel | ø 2300 mm. |
| Total weight dry | 9000 kg. |
| Total weight with water | 12000 kg. |
| Trench depth up to | 1000 mm. Adjustable with the stabilizing wheels. |



| | |
|---|---|
| Discus wheel | ø 2300 mm. |
| Total weight dry | 4000 kg. |
| Total weight with water | 7000 kg. |
| Trench depth up to | 400 mm. |

Figure 23. Large- and small-size disc wheels

the disc wheels in use can be made heavier as required by partly filling them with water.

113. The method of applying the furrowing equipment is as follows (the time between the various furrowing operations will vary according to factors such as time of year, influence of the seasons, thickness of layers, and composition of the dredged material):

a. About 2 months after the material has been deposited, the first set of tracks is made with the Amphirol cylinders in the still very soft mud. In this way, parallel depressions 5 to 10 cm deep are formed. To determine the direction of the furrow on the site, attention must be paid to the (slight) downward inclination of the mud surface in the direction of the weir. Surface water must be drained off in this direction. Along the edges of the site, a cross furrow links up the parallel ones. With each run of the Amphirol, two tracks are made 2 m apart (distance between the cylinders). After every run, the vehicle shifts 5 m. This creates a furrow pattern with widths alternating between 2 and 3 m (avg 2.5 m).

b. In many cases, a second round of Amphirol furrows is made 3 to 4 months after the dredged material has been deposited. The same tracks are followed. If necessary, the Amphirol is loaded with ballast to deepen the furrows.

c. Five to six months after disposal, the small disc wheels 2.5 m high are used. With these, all the tracks made with the Amphirol are further deepened to about 30 cm. At this stage, great care has to be taken to ensure that the furrows are properly linked with the perpendicular furrows along the edges of the site. If necessary, furrows must be joined up manually to ensure their proper functioning (drainage).

d. About 8 months after disposal operations, the furrows can be deepened with the large disc wheel. One in four of the existing furrows is deepened in such a way that the center-to-center spacing between the furrows of the large disc wheel is 10 m. A maximum furrow depth of 60 cm can be obtained. Furrowing with the large wheel is always performed on the last layer of mud fed into a site. If one or more layers are still to follow, the large wheel is not always used. In particular, when the layer deposited is thin (1 m or less of fresh mud) and when other circumstances (the season) are favorable, furrowing with the large wheel is generally omitted. This is chiefly the case when more mud is soon to be brought to the site.

e. When the layer to be dewatered is the highest layer of the disposal area, the procedure mentioned in a above is combined with seeding of grass.

114. A special subject is the accessibility of a disposal area after the disposal operation. This subject is of paramount importance if the disposal area is narrow and the operation advances rapidly, such as in the construction of road foundations. A method for the assessment of the accessibility is given in Nieuwenhuis[4] and is presented in an abbreviated form in Appendix E.

## Unconfined Disposal Areas

115. In Europe, material from maintenance dredging is not disposed in unconfined areas for the following reasons:

a. Disposal areas are so extremely difficult to obtain that use solely for unconfined disposal is uneconomical.

b. The saline dredged material will disturb the salt balance of the surrounding arable lands.

Material from capital dredging, when not disposed at sea, is also usually disposed in confined areas; however, occasionally, when there is no danger of salt intrusion into surrounding arable land, it is disposed in unconfined areas. Examples of such unconfined disposal near Rotterdam are:

a. Construction of a sand dam as part of the breakwater near Hook of Holland.

b. Reclamation of the Maasvlakte.

c. Beach nourishment near Hook of Holland.

These are discussed in the following paragraphs.

### Construction of a sand dam

116. The optimum layout of the harbor entrance to Rotterdam Europoort was determined on the basis of hydraulics investigations. This layout consisted of a straight northern breakwater and a curved southern breakwater. The latter allowed for the reclamation of the Maasvlakte, an industrial and harbor area that is still in a stage of

development. It soon became apparent that it was not necessary to construct the southern breakwater as a rubble mound over its full length; since the southernmost connection with the mainland would be almost completely protected, it was decided to construct a beach type of sea defense. This part of the breakwater, constructed prior to the completion of the rubble mound breakwaters, had the character of a sand dam deposited into the sea (Figures 24, 25, and 26).

117. Although in this case the dredged material was not a by-product of a dredging cycle, the project is so interesting that a few highlights are mentioned here. A more complete description is given in Dixhoorn et al.[5] The main conclusion after the operation was that, although tidal currents were running parallel to the coast, the sand losses over the whole project were not more than 15 to 20 percent. This may, at least to some extent, be the result of natural deposition along the dam.

118. The material used for the construction of the sand dam was dredged from deep pits in the Brielse Gat. The bottom material mainly

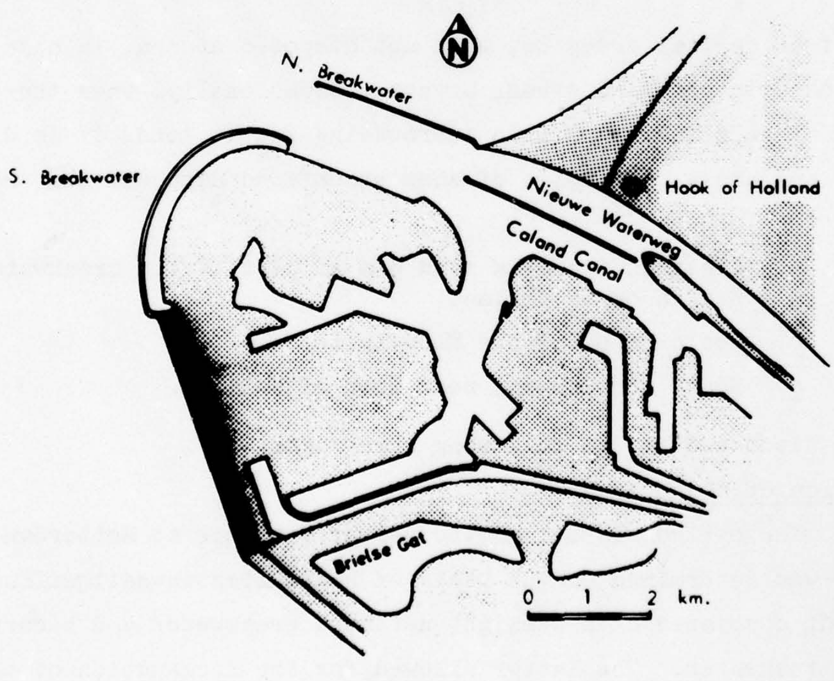



Figure 24. Sand dam in Europoort

Figure 25. Aerial view of sand dam in Europoort

consisted of sand with a diameter from 150 to 250 μ. This resulted in underwater slopes of the dam in the order of 1:10 to 1:60, depending upon grain size (Figure 27). Later on the slopes flattened out to 1:50. The sand was dredged by means of plain suction dredges from a depth of up to 40 m below sea level. The work was carried out by two suction dredges with a combined output of approximately 3000 $m^3$ of sand per hour (104 hours per week) and a mixture density on the order of 1250 $kg/m^3$. The total amount of sand in the dam amounts to approximately 35 million $m^3$. At present, the outer slope is used as a recreational

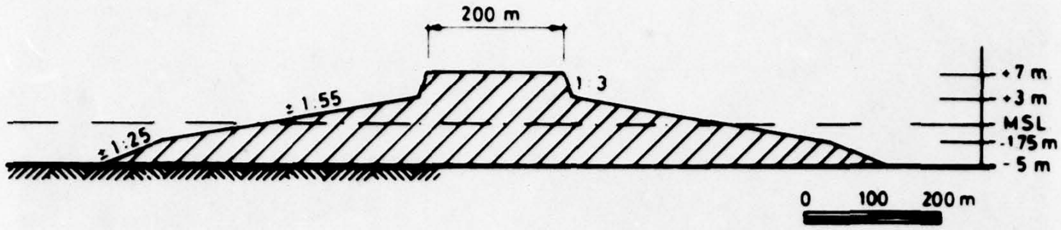



Figure 26. Cross section of sand dam in Europoort

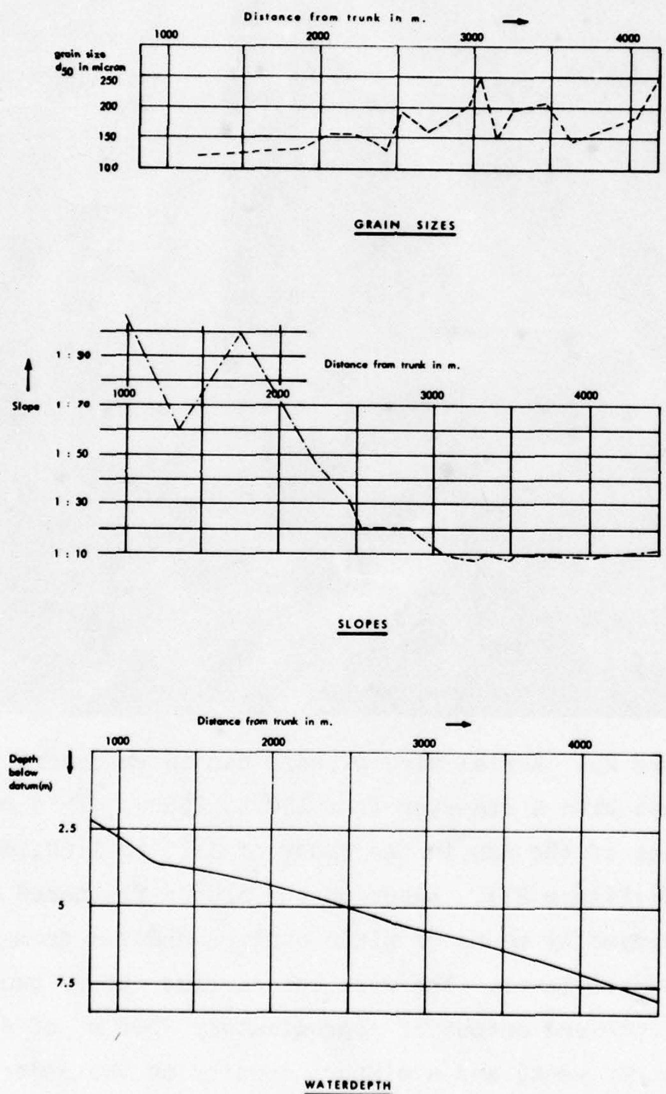



Figure 27. Grain size, slope, and water depth of sand dam in Europoort

beach. Protection against wind erosion is similar to the method mentioned under beach nourishment at the Hook of Holland.

Reclamation of Maasvlakte

119. Along with the construction of the sand dam, but slightly behind the dam, reclamation of the Maasvlakte had to be started to dispose of dredged material from harbor basins under construction. In this case the reclamation was really a by-product of the dredging operation. Here also the principle of unconfined disposal was applied, although the dump was more or less protected by the sand dam.

Beach nourishment
at the Hook of Holland

120. After completion of the Maasvlakte reclamation, there still was an excess of dredged material originating from new harbor basins and the final harbor entrance. Because morphological changes north of the new breakwaters were foreseen as a result of the interruption of the net northward littoral transport, it was decided to use at least a part of the excess material to reinforce the dune coast at the Hook of Holland over a length of 3500 m (Figure 28).

121. Approximately 15 million $m^3$ of material was pumped from Europoort to the disposal area via three pipelines of 700 mm diameter submerged under the Nieuwe Waterweg at a depth of NAP -22 m* (Figure 29). Material was dredged by trailing suction hopper dredges and other equipment and dumped in front of plain suction dredges, which pumped the material into the work. Occasionally other types of dredges were used.

122. Since the material originated from different locations in the harbor area and the approach channel, its quality varied considerably. The disposal program was adapted in such a way that clean sand supplied by trailing hopper dredges from the new harbor entrance was used for the outer parts of the beach, whereas silty sands and even small amounts of clay were used to construct 456,000 $m^2$ of artificial dunes. The working program was such that the public's use of the

---

* NAP is a survey datum that approximately coincides with mean sea level (msl).

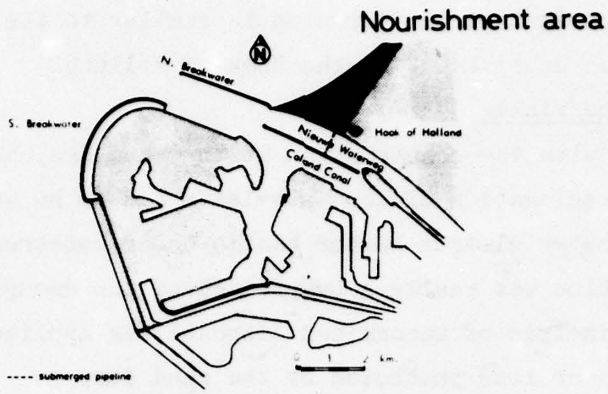



Figure 28. Beach nourishment at the Hook of Holland

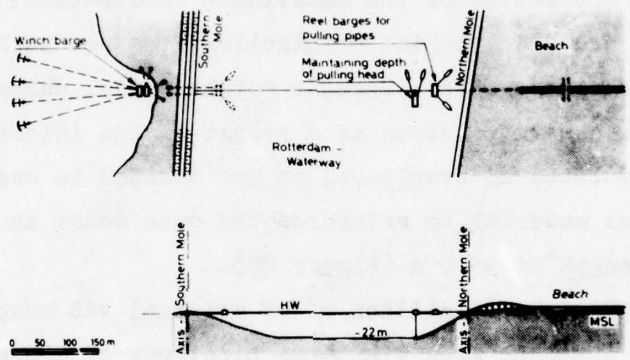



Figure 29. Construction of a pipeline through Rotterdam Waterway

recreational facilities was uninterrupted (Figures 30 and 31). Sand losses amounted to approximately 20 percent. Slopes were in the order of 1:20 and 1:30 during the spouting (Figure 32). As this is steeper than the natural slopes of the foreshore, approximately 2 million $m^3$ of additional sand was dumped with shallow draft trailing hopper dredges (Figure 33) at a depth of approximately -3 to -4 m msl.[6]

123. To counteract wind erosion, the newly built dunes and slopes were immediately planted with marram (Ammophila), four plants/$m^2$. The horizontal areas were protected by straw (0.5 kg/$m^2$) and seeded with the so-called Europoort grass mixture (0.01 kg/$m^2$).

124. The interesting aspect of this work is that a most valuable

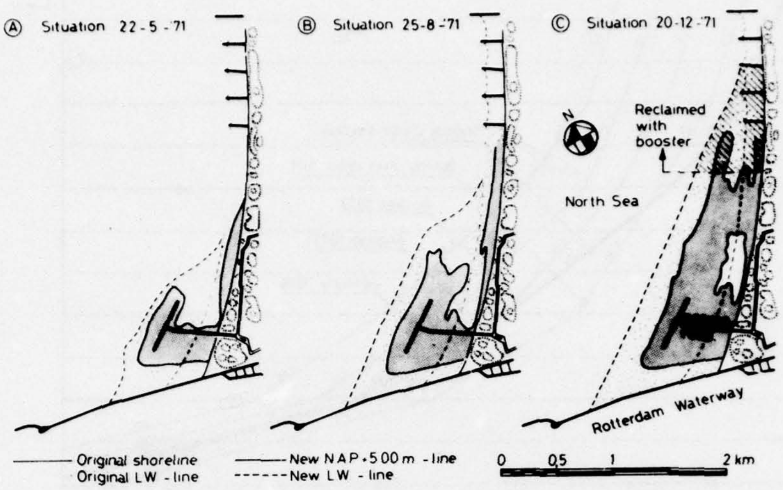



Figure 30. Construction phases for beach nourishment at Hook of Holland

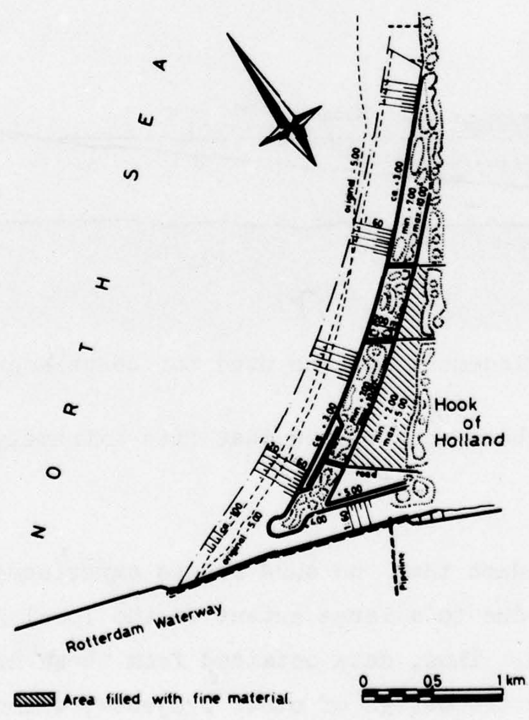



Figure 31. Detailed layout of beach nourishment at Hook of Holland

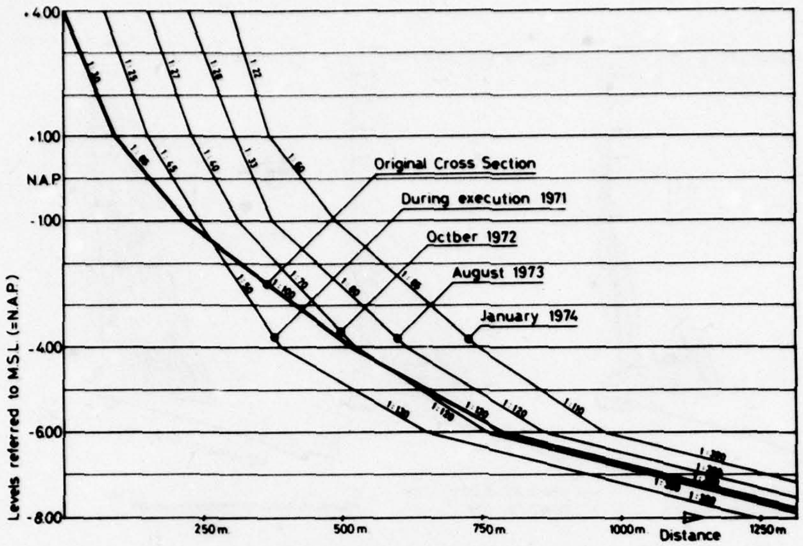



Figure 32. Slopes of beach nourishment
at Hook of Holland

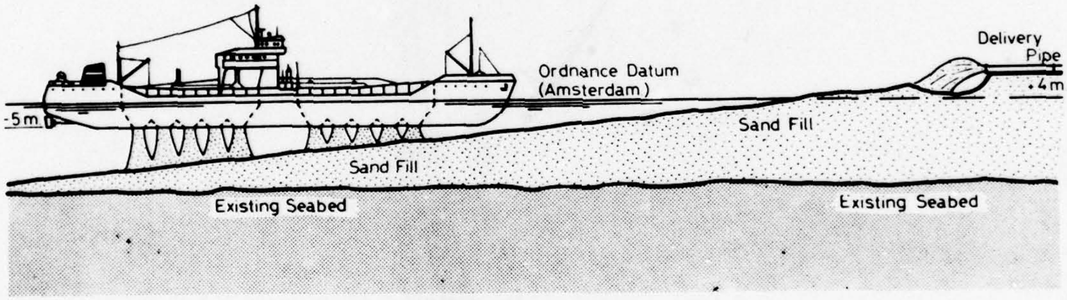



Figure 33. Placement methods used for beach nourishment

recreation area has been constructed that fits extremely well in the natural landscape.

Sand losses

125. It is evident that the sand losses experienced during the above projects were due to a large extent to the local hydrographic and hydraulic conditions. Thus, data obtained from these experiences cannot be used directly for the design of other projects, without further analysis. If, however, a further analysis is made, it should be realized that the losses during construction of the sand dam or similar works are also a function of the capacity of the sand supply.

## Disposal in Lakes and Pits

### Lakes

126. As a result of the dredging of sand for construction purposes, in many places a number of deep lakes have been created or existing lakes have been deepened considerably. Such lakes may reach depths of 30 to 40 m. In the deeper parts of these lakes, anaerobic conditions may develop due to temperature-induced stratification, and, in autumn, temperature inversions may bring the anaerobic water to the surface causing objectionable odors. These problems particularly arise in a condition of eutrophy, due to the presence of phosphates.

127. Although the situation can be improved by relatively simple techniques, e.g., artificial aeration, it is widely considered more practical to reduce the water depth by dumping debris or other material into the lakes. Along these lines, the Harbor Department of the Municipality of Rotterdam is considering the use of dredged material for this purpose. At present such a project is being studied for the Oostvoornse Meer and special precautions are envisaged to prevent the silt from polluting the lake and thus restricting existing recreation activities.

128. The use of dredged material for filling the deeper parts of such lakes has three advantages:

- a. The dredged material is permanently extracted from the hydrological system and can be stored safely.
- b. The problem of stratification and inversions is solved.
- c. Recreation is promoted by the absence of extremely cold undercurrents with a reduction of the risks to swimmers.

129. In this respect, a preliminary idea has been developed to discharge silt into an enclosed area and then pump the diluting water out of this area. Further, the disposed material can be covered by sand layers. Contamination of the water due to the disposal of dredged material, heavy metals, pesticides, oil, etc., must remain within acceptable limits from a chemical and hydrobiological point of view. Before such a project is undertaken, however, it is proposed to carry out

investigations under conditions similar to the natural circumstances (also see paragraphs 180-183).

Pits

130. The disposal of dredged material into pits can be considered as a special type of unconfined disposal. For the purpose of the present study, pits are defined as isolated deeper sections of rivers and harbor basins. The advantages and disadvantages of using these pits for disposal purposes are basically the same as those mentioned for unconfined disposal and disposal at sea. A special use of such pits is made when they are used to allow the dredged material to consolidate and to function as borrow pits for land-based disposal afterwards.

## Disposal at Sea

131. There are numerous possibilities for the selection of a dump site at sea. The following factors play a role:

- a. There is a risk that the dredged material dumped at sea will return into circulation as a result of the pattern of the current. The result would be that the same material is dredged more than once. This problem is closely related to local circumstances and will have to be considered in connection with a study of site-specific natural conditions.
- b. The transport costs must be considered. To reduce the transport costs, nearshore disposal should be considered if even a certain percentage of recirculation may be acceptable.
- c. Last, but not least, the environmental conditions are of importance. The disposal of some components of contaminated dredged material is subject to rigorous international restrictions or is even completely prohibited. The environmental aspects will be discussed elsewhere in this report.

## Cost Aspects

132. It is very difficult, if not impossible, to give an accurate and generally applicable assessment of the cost of dredging and disposal area operations. In the first place the cost can differ considerably

from place to place, depending on local conditions. Secondly, the output in different areas will vary to a large extent; and, thirdly, if costs are given, the figures may soon lose their significance as a result of inflation and variations in rates of exchange between different currencies. Therefore, in this report only remarks of a general nature will be made on the cost aspects.

Dredging operations

133. The costs of dredging operations are generally divided into mobilization and demobilization charges and operating costs. These costs can be subdivided into a large number of smaller items such as rent, insurance, maintenance and repairs, wages, fuel, harbor dues, management, etc. Over and above these different costs, risks, profits, and taxes are added.

134. In order to assess the weekly charges for rent, maintenance, and repair, the dredging equipment in The Netherlands is classified and a standard value is determined by applying certain criteria. On the basis of this standard value, the cost of rent, repair, and maintenance can be calculated.[7] Especially in case of long-term contracts, special agreements on the prices are negotiated.

135. To arrive at the unit cost of dredging operations, the output has to be estimated. Again, presentation of concrete figures does not seem to be very useful because the output of one and the same dredge may vary considerably from one place to another. Factors that play an important role are properties of the sediment to be dredged, depth, thickness and width of the cut, debris and obstacles (ropes, cargo, etc.), and anticipated delays (shipping, tides, etc.).

Disposal area operations

136. The distinction between the cost of dredging and the cost of disposal of dredged material is not well defined as it is difficult to indicate where the dredging operation ends and where the disposal operation starts. Further, it should be mentioned that the dredging and the disposal operations are continuously influencing one another. The cost of transport (barge transport versus pipeline transport), the suitability of a certain dredge for a certain method or place of disposal, the

availability of (and distance to) reclamation sites, and the cost of rehandling are together determinative for the optimum dredging and disposal methods. The allocation of cost to certain parts of the dredging and disposal system is a complicated matter that cannot be solved with mathematical accuracy. To give an indication of the relative cost levels, it is generally accepted that barge transport is cheaper than pipeline transport (including the cost of rehandling) for distances in excess of approximately 3 km.

137. Regarding disposal area operations, it is nevertheless possible to mention a number of cost items that clearly belong to this part of the entire dredging process. The cost of disposal area operations starts with the acquisition of land.

138. The price of buying or renting land for disposal areas depends on the land use. In general, intensively used areas are too expensive. This is caused by the direct cost of the land as well as by the presence of a costly infrastructure that would have to be removed. Much of the land around cities, villages, and harbor areas is to be acquired by the authorities anyhow in order to make it suitable for extension of residential, industrial, or harbor facilities. Afterwards, it is sold again or hired at a cost that basically covers the relevant expenses.

139. Whatever the method or the goal of the land acquisition may be, it is in the best economic interest that the disposal areas be used again as soon as possible and that the largest possible quantity of dredged material be stored. Therefore, the special measures to improve dewatering, ripening, and consolidation are justified. Their costs, however, belong clearly to the disposal operation.

## PART VII: PRODUCTIVE USES OF DREDGED MATERIAL

140. The disposal areas in western Europe are used for productive purposes, without exception. The most common location of disposal areas is in association with harbor or industrial improvements. The relatively low bearing capacity is no problem as in most cases pile foundations for buildings and structures would be required anyhow. Other productive associations of disposal areas are agriculture and/or recreation sites. Except for the investigations in Rotterdam, which are reported in Part IX, no other scientific analysis of the influence of contaminants on plants seems to have been carried out in Europe. In Rouen trees were planted on an experimental basis, but results have not been related to contamination of the fill material.

141. Locally, dredged material is sometimes sold from disposal areas, but this is generally restricted to small quantities of sand. It has not been the practice to use the same disposal area for deposition of dredged material on a continuing basis by removing and selling the material. Around Rotterdam, former disposal areas are used for:

- a. Residential areas (Figure 34).
- b. Recreational areas (Figure 35).
- c. Industrial areas (Figure 36).
- d. Soil improvement for agricultural use (Figure 37).
- e. Soil delivery for layout and maintenance of parks and public gardens and for covering new sand-filled areas.

### Agricultural Aspects

#### Forestation of harbor mud

142. The Municipality of Rotterdam initiated in 1969 an investigation by the "koninklijke Nederlandse Heide Maatschappij"* into the possibilities of planting trees on land recently raised using material

---

* Koninklijke Nederlandse Heide Maatschappij is an organization specializing in agricultural engineering.

Figure 34. Residential area on former disposal area

Figure 35. Recreation area on former disposal area


Figure 36. Industrial area on former disposal area

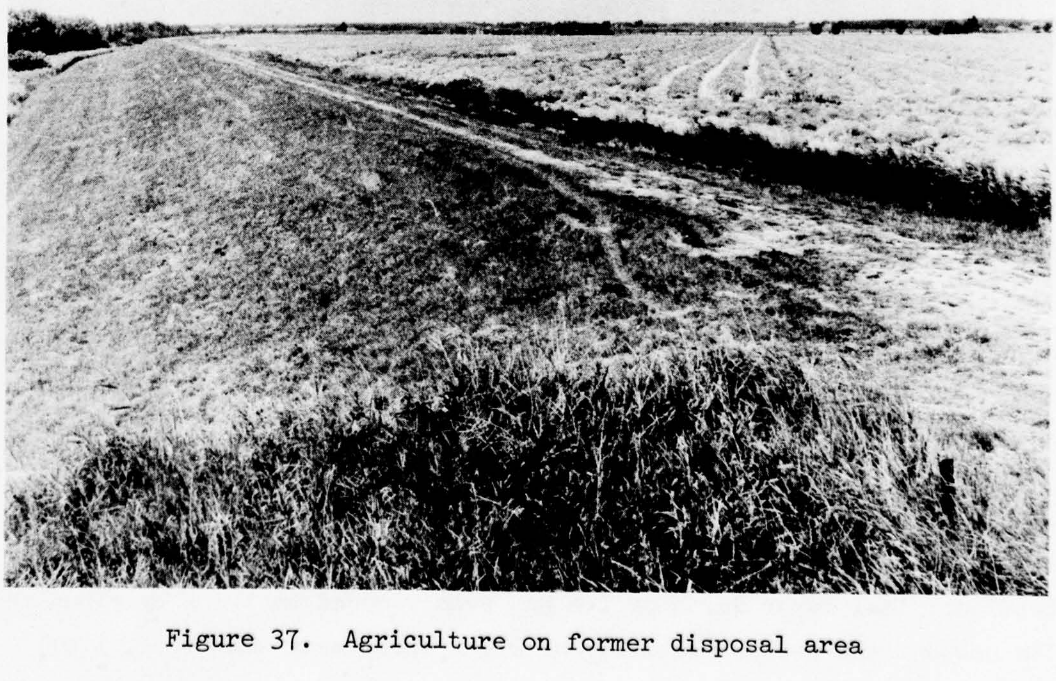


Figure 37. Agriculture on former disposal area

from maintenance dredging. To this end, a testing site was prepared in Broekpolder. A comparison is made between the growth of pioneer and nonpioneer species. Pioneer species are those that can be planted in areas without other (high) vegetation. They can grow on a poorly developed soil profile (partly ripened). The pioneer species grow fast and can be cut down a few years after planting. Nonpioneer species are generally planted after some vegetation has been developed. They grow slowly and require a well-developed soil profile. Two ways being compared to treat the soil are (a) an early planting without preparation of the soil, except for dewatering, and (b) planting after 1 year of intermittent mechanical mixing of the upper layer.

Study group investigations

143. It was considered interesting to investigate whether or not the gain in time by early planting is being balanced by the better growth under a different condition of the soil (better ripening, breaking up of horizontal layers). A study group (Studiegroep Beplantingsproef Broekpolder) was formed to monitor the investigations. The following paragraphs summarize reports by Stuurman and Peeters, members of this group.[8,9]

144. The history of the site. The site was constructed in several lifts. The subsidence of the original surface, the total layer depth, and the total subsidence were measured. The following data give a presumable representative overall view of the conditions of the testing site:

| Year | Layer Depth (unconsolidated) | |
|---|---|---|
| 1960 | 1.10 m | 7.00 m |
| 1961/1962 | 1.60 m | |
| 1965 | 2.30 m | |
| 1966/1967 | 2.00 m | |

The subsidence of the original surface is 60 cm. In July 1970 the total original layer depth of 7 m had been reduced to 5.3 m by ripening. The new surface had an elevation of 2.4 m above mean sea level, i.e.,

4.7 m higher than the original level. After the last lift, the site was furrowed by means of the disc wheel. In December 1969 the soil was investigated to determine its composition and ripening depth. The soil is, except for some very thin silty layers, rather homogeneous. The composition in percent of dry matter is as follows:

a. Organic matter, 10 to 14 percent.

b. Lutum, 20 to 26 percent.

c. Lime, 11 to 15 percent.

145. Test procedure, planting, and soil treatment. The testing site consists of two parts, A and B, each 100 m square. The site is for the greater part encircled by a ditch of 1.1 m depth. Dewatering on a smaller scale is being taken care of by furrows having a depth of 60 cm. The western part (A) was planted in March 1970 after a slight bottom treatment. The plant composition was one third principal tree species, one third black alders, and one third shrubs (12 species). The planting grid was 1.3 × 1.3 m. Each principal tree such as ash, maple, and oak (nonpioneer) and elm and poplar (pioneer) covered an area of 20 × 100 m. The age of the different trees vaired from 1 to 3 years. In 1970 the eastern part (B) was overgrown with weeds. In March 1971 this site was planted after the soil had been tilled twice to a depth of 0.70 m. The planting was the same as in A.

146. Development of the soil. Since 1969 soil samples have been taken periodically to examine the degree of ripening and salinity. Except for the first test, samples were taken from a depth of 0.3, 0.6, and 0.9 m.

a. Ripening. The degree of ripening can be ascertained by calculating the n number.

$$n = \frac{A - p(100 - L - H)}{(L + b)H} \qquad (7)$$

where

A = water content as a percentage of the dry weight

p = percentage of water combined with noncolloid material (i.e., dry matter minus lutum and organic matter)

L = lutum percentage

H = organic matter percentage

b = capacity of organic matter to combine with water divided by capacity of the same weight of lutum

The constants b and p depend on the composition of the sediment.[10] In this particular case $b = 3$ and $p = 0.3$ seem a good combination. Ripening of section A and B as a function of depth and time is shown in Figure 38.

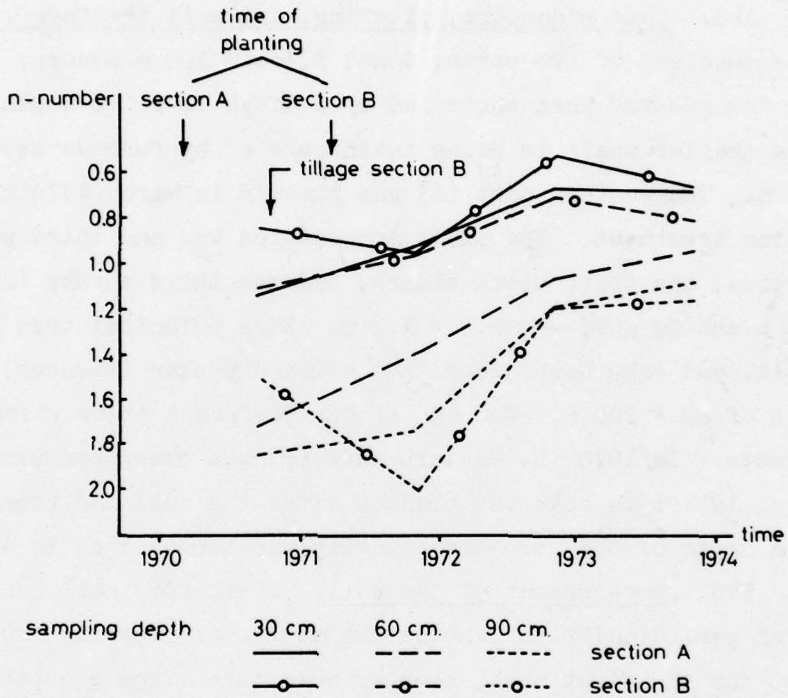



Figure 38. Ripening as a function of depth and time

b. Ripening versus n . The following columns show the relationship between qualitative ripening stage and the n number.

| Ripening Stage | n Number |
|---|---|
| Ripened | < 0.5 |
| Nearly ripened | > 0.5 < 0.9 |
| Half ripened | > 0.9 < 1.4 |
| Nearly unripened | > 1.4 < 2.0 |
| Unripened | > 2.0 |

c. Depth of ripening at the time of the planting. In the spring of 1970, the depth of ripening had reached 40 cm. The weeds and the tillage on section B added another 20 and 10 cm, respectively, before B was planted in 1971. At that time the ripening depth in section A was still only 40 cm, as the young trees did not boost evapotranspiration very much.

d. The pace of the ripening. Sections A and B are clearly two different areas. In section B the ripening depth is up to 60 to 70 cm, notwithstanding a somewhat higher groundwater table than in section A. In section A the roots of the trees increased the depth by 20 cm, from 40 to 60 cm. The measured values of $n$ for several years can be found in Figure 38. The degree of ripening has generally increased throughout the years. In October 1971, because of tillage, the values of $n$ for a depth of 30 and 60 cm were almost equal in section B.

147. Salt. The silting of a harbor occurs in a salty or brackish environment. Consequently, a certain amount of salt can always be found in the dredged material and later in the disposal area. The salt is leached out by rainwater. The salt content can be defined using a C-number (weight percentage of NaCl in the groundwater). This has a drawback as the value changes with changing moisture content. In this investigation the conductivity of a saturated sample has been used to indicate salt content. Because of its solubility, salt is very mobile (downwards with drained rainwater, upwards with water to replenish water evaporated from the upper layer). Figure 39 shows conductivity values for sections A and B for several years. On the whole the conductivity, or indication of the salt content, diminished with time. In a dry summer it can increase because of replenishment of the evaporation surplus by water from deeper (more salty) layers. The test in spring 1973, performed because of the high salt content in the end of 1972, showed a considerable decrease in salt content during the winter.

148. Micromorphological investigation. Some interesting phenomena partially connected with the ripening were observed in thin slices of the soil. During the process of ripening, iron compounds were formed along the cracks by oxidation and precipitation of iron compounds in solution. At several spots one could also observe gypsum crystals. More important for the growth of the trees, i.e., for the possibilities

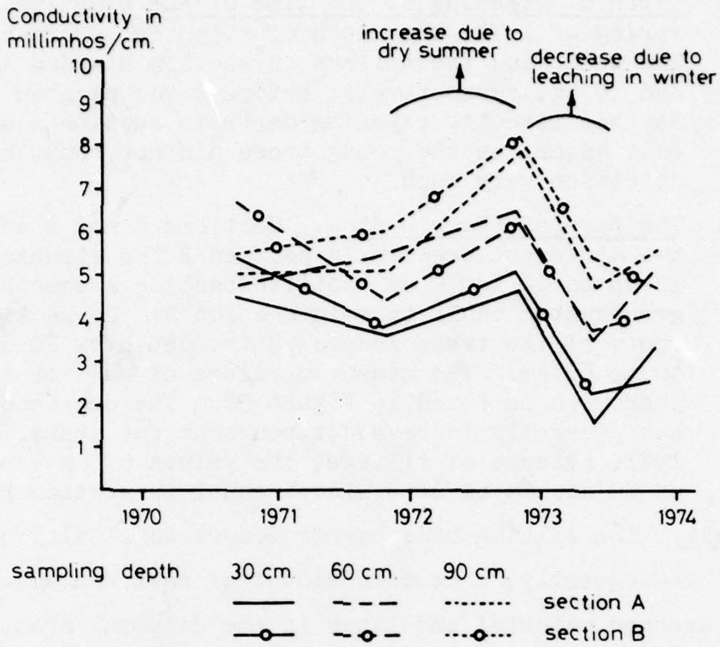



Figure 39. Conductivity as a function of depth and time

of the development of roots, is the locally decreased compactness caused by tillage. Compact layers prevent critical penetration by roots and normal tree growth. A more intensive tillage breaks up the compact layers and permits normal root growth.

149. Preliminary evaluation of the development of the soil. The rate of growth showed that delaying the planting until the soil was tilled did not yield better results than planting in an early stage without tillage. This might be dependent upon the fact that the dredged material contained a high percentage of clay minerals. The sand layers were thin, and the shrinkage cracks dissected the sand layers. The roots could use the cracks when the sand layers were too much of a barrier. This could be the reason for the small difference in growth between sections A and B. In soils of this composition, tillage is not necessary. Whenever the soil of the disposal area contains more sandy material, tillage is probably a necessity. No damage because of salt was observed. At the end of 1972, the root depth was such that no negative influence on growth was expected. One can surmise a certain amount

of damage in a very dry year, keeping in mind the increase of the root depth and the fact that the salt content at a depth of 0.9 m was still the same as in the beginning.

150. Development of plants and trees. Every year the state of the leaves and the vitality of the trees on the testing site are determined. The growth is measured and during the first years the development of the vegetation was closely followed. This will be elaborated in paragraphs to follow. In comparing the growth in A and B, one must pay attention to the following characteristics mentioned in Table 9.

Table 9

Characterization of Planted Areas

| | Section A | Section B |
|---|---|---|
| Planted | March 1970 | March 1971 |
| Ash | Age 2 years<br>height 60 cm | Age 4 years<br>height 200 cm |
| Deep tillage | None | Up to 70 cm |
| Influence of wind | More | Less |

151. Evaluation during the first year. The percentage of healthy, withering, and dead principal trees is shown in Table 10. After the

Table 10

Percentage of Healthy (H), Withering (W), and Dead (D) Principal Trees After 1 Year of Growth

| Species | Section A H | Section A W | Section A D | Section B H | Section B W | Section B D |
|---|---|---|---|---|---|---|
| Ash | 85 | 8 | 7 | 96 | 4 | 0 |
| Maple | 97 | 3 | 0 | 88 | 9 | 3 |
| Indigenious Oak | 69 | 12 | 19 | 69 | 9 | 22 |
| Elm | 79 | 0 | 21 | 95.5 | 4 | 0.5 |
| Poplar "Robusta" | 94 | 0 | 6 | 95 | 2.5 | 2.5 |
| Poplar "Darskamp" | 49 | 1 | 50 | not planted | | |
| Black Alder | 35 | 11 | 54 | 77 | 13 | 10 |

first year some shrubs were evaluated as follows in both sections:

| Rating | Shrub |
|---|---|
| Good | Hawthorn, rowan tree, bird cherry, red cornel |
| Moderate | Sweet briar, hazel |
| Poor | Sweet chestnut |

Some of the shrubs were largely damaged by rabbits eating the bark.

152. Development during the first 3 years. Judged by the state of the leaves, the development of the different trees is summarized as follows:

a. Principal trees. Section A: ash, maple, oak, and elm had a slow start. The development in the second year was good, and in the third year it was very good. Poplar had reached a good stage of development earlier. All species suffered when exposed to the westerly winds. Section B: maple, oak, and elm had a good first year. The following 2 years were good as well, although elm and maple suffered some leaf damage. Ash, because of its age, did not grow at first. Even in the third year, the growth was only moderate. Poplar did very well. Wind had little influence.

b. Supplementary species. Development of black alder, as far as state of leaf and growth are concerned, was moderate to poor both in sections A and B. The growth in height was acceptable.

c. Shrubs. Ignoring damage by animals, the species in A and B were rated as follows:

| Rating | Shrub |
|---|---|
| Good-very good | Hawthorn, rowan tree |
| Good | Hazel, bird cherry, red cornel |
| Moderate-good | Sweet chestnut |
| Moderate | Sweet briar |

Note: The specimens of ash, oak, and alder showed quite some differences in A as well as in B. Neither the healthy nor the bad specimens appeared in concentrated locations; they were found next to each other. An analysis of the leaves did not explain the cause. A deficiency of manganese can possibly be blamed. The differences became less apparent in later years.

153. Preliminary evaluation and summary. The percentage of failure was low in both sections A and B. The development of all principal species was good after some initial difficulties (especially in A). The species of A suffered more damage from wind because of the more exposed location. Some species like sweet chestnut, red cornel, hazel, and oak benefited from shelter. The better conditions for growth in B (tilled, more ripened, less exposed) were especially noticeable in the first year (Figure 39), yet the average heights of trees and shrubs in B were still less than in A. Prevention of weeds by mechanical means (shallow plowing) or by herbicides proved superior to prevention by mowing. Maple and elm reacted in a very positive way, oak being the only exception. On well-drained clayey soils, planting early yielded good results. The same planting a year later on a soil tilled at great depth did not show better overall development. Because of luxurious growth of weeds on this kind of land, weed prevention during the first 2 years is considered necessary to healthy development of shrubs.

## Conversion of Dredged Material

### Production of topsoil

154. Kralingen. Every year the Municipality of Rotterdam needs 100,000 $m^3$ of soil to lay out and maintain parks, gardens, etc. After a couple of years, ripened dredged harbor mud is mined for this purpose and transported to the green zones in and around Rotterdam. Part of the filled site at Kralingen disposal area is used as long as the site is not required for another purpose. This is a cheap way compared with the normal way. If the area of the site is sufficient, a continuous supply of soil is available. The different lots are alternately filled with dredged material, dewatered, and dug out. The greater part of the site at Kralingen needs to be made suitable for building as soon as possible. Because of this, only 150,000 $m^2$ is left to produce clay. This area is too small for a continuous delivery of 100,000 $m^3$ of soil per year. Laboratory tests on the soil to be dug at Kralingen

showed that the soil is perfectly suitable for horticulture. (This was already known from past practice.) Results from the analysis are:

| | | |
|---|---|---|
| a. | pH - KCL | 7.3 |
| b. | $CaCO_3$ | 13.5 |
| c. | Organic matter (humus) | 8 to 10 percent |
| d. | Lutum | 25 to 30 percent |

The state of fertility of the soil was:

| | | |
|---|---|---|
| a. | $CaCO_3$ | high |
| b. | Magnesium | high |
| c. | pH | high |
| d. | Potassium | good |

The soil is only suitable for use in horticulture if it is ripened to a sufficient depth. This has been checked by hand borings (Figure 40). From the results it was found that the soil was immediately suitable to a depth of 0.5 m. By accelerating the drainage along the boundaries of the disposal area and by the removal of the upper layers, the ripening process was accelerated in such a way that approximately 1 m of soil could be removed 1-1/2 to 2 years after disposal.

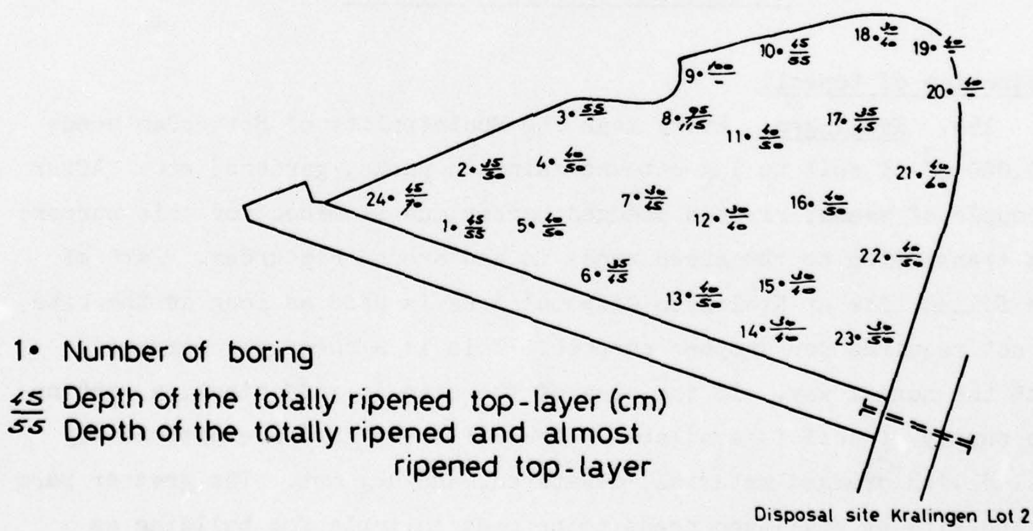



Figure 40. Depth of ripening at Kralingen

155. Maasvlakte. The industrial area Maasvlakte was reclaimed from the sea by disposal of sand. For the completion of the area,

topsoil will be required to cover sand flats for levees and for green zones. To provide the required topsoil, the Municipality of Rotterdam constructed a disposal area, subdivided in four sections of 4 ha each. Dredged material from Europoort is discharged into this disposal area. The material is dredged by a trailing hopper suction dredge and dumped in a nearby pit in one of the harbor basins. After filling of this pit, the material is reclaimed by a stationary suction dredge. At present, two of the four sections have been filled. Ripening in this case is very fast because of the following reasons:

a. Extremely thin lifts (0.75 m).

b. Permeable subsoil (reclaimed sand).

c. Application of dewatering techniques as mentioned in paragraphs 107-114.

Fabrication of bricks

156. On an experimental basis, bricks were fabricated from ripened dredged material from the Rotterdam harbors. If the experiment proved successful, a certain quantity of harbor mud could possibly find a new useful application. Before the experiment, it was already clear that the production of bricks would require only a very small percentage of the annual siltation. The total annual amount of dredged material for Rotterdam is enough to supply the whole brick industry in The Netherlands with raw material. At the same time, it also was clear that the distance between the dredged material and the existing brick factories was economically prohibitive and that the construction of a new factory, closer to the source, was not presently feasible for political and economic reasons.

157. The first phase of the investigation was to perform a basic experiment in a laboratory. The experiment was monitored by the "Stichting Technisch Centrum voor de Grofkeramische Industrie" (Technical Centre for the Keramic Industry) at Arnhem. The results were rather good. Thereafter, in the summer of 1975, about 6000 bricks were made in a factory. For this purpose ripened harbor mud was used from the disposal area Kralingen taken from the top of a layer. The results of the test are described as follows:

a. Rather large differences were found in the dimensions of the bricks; this can be improved probably by a better mixing of the soil.

b. The strength of the bricks was reasonable.

c. The bricks showed a wide variation in color.

d. The sulphate content was rather high.

Mixing of the ripened dredged material with other clays would improve the properties of the bricks. In view of their mechanical properties, the bricks from the test could be used for the construction of inner walls and in some cases for use in ornamental masonry.

## Polders

158. It has been mentioned before that for centuries polders have been developed in Holland, made possible by specific geological and hydrological conditions. The elevation of these polders is not lower than 6 m below sea level; horizontal semi-impervious layers prevent seepage to a considerable extent. The top layers of the bottom of the lakes often consist of unconsolidated layers of mud. As soon as the polders are dry, the process of ripening starts. The process is exactly the same whether it concerns a new polder or a confined disposal area filled with mud from maintenance dredging. Much information is available, mostly of an agricultural nature, on the construction and installation of these polders since a lot of research has been done by a government agency, De Rijksdienst voor de IJsselmeerpolders.

159. A discussion was held with Ir. H. Smits and Ir. R. J. Glopper[11] of the "wetenschappelijke afdeling" (scientific department) of the aforementioned agency. The gist of this conversation was that it is possible to forecast whether mud found at the bottom of a waterway will be suitable for vegetation once it is brought to a site. Some factors considered in such a forecast include:

a. The drying process must be irreversible so that once cracks are formed, they do not close again. This is influenced by the kind of clay mineral.

b. In the presence of sulphur compounds, there is a danger

that the soil might turn acid if the quantity of lime is insufficient.

c. The amount of lutum and humus is of great importance as far as crack formation is concerned.

d. The climate.

e. The hydrological regime.

160. Once a polder is dry, it lies fallow for some years until the upper layer has strengthened enough to support the vehicles that make the furrows. This time span can be diminished by the sowing of seed. The evapotranspiration caused by this and other plants is an important factor in drying the upper layer. Anything that furthers dewatering, such as a well-controlled drainage system and pervious sublayers, is beneficial in accelerating the development of the top layer and in preventing unfavorable side effects. Thus, mosquitos and foul smells persist only as long as the top layers are still very wet. No measures other than a rapid dewatering have been taken in the Dutch polders to prevent the breeding of insects.

161. The scientific findings have for the greater part been published in "Van Zee tot Land" (From Sea into Land), mostly in the Dutch language. Issue No. 50 on subsidence is written in the English language.[11] A summary of an article from the No. 32 issue[12] on ripening is added as Appendix F. Most findings in developing polders or disposal areas are comparable, but the time consumption allowed in the development of disposal areas is mostly shorter. This can be understood from the fact that the demand for land is greatest in the densely populated industrialized zones around harbors.

## PART VIII: CONTAMINATION OF DREDGED MATERIAL

### General

162. In this part of the report, the sources of contamination will be discussed, as well as the degree of contamination they cause. Until 1970 salt intrusion was the only environmental effect taken into consideration in Europe. About 1970 several European countries started discussions about the environmental effects of the contamination of the sea by substances that are liable to create hazards to human health or to harm living resources and marine life. These discussions led to regional conventions for the North Sea and the northeast Atlantic. About 1972 some harbor authorities initiated surveys to determine the presence of contaminants in the dredged material. Of special interest was the contamination of oil, heavy metals, and pesticides. Contamination by these agents, as well as by salt, is discussed in detail in this section. In addition, pertinent European legislature is discussed.

163. From discussions with government agencies concerned, it appeared that no criteria are yet available from which the quality of the dredged material can be evaluated.

### Contamination in Europe

164. From Table 11 a general impression can be obtained of the degree of contamination of dredged material in several European ports.

### Contamination in Rotterdam Harbor

165. Special attention is paid to the pollution in the Rotterdam Harbor area because the degree of pollution there is the highest in Europe. Situated in the estuary of the Rhine River, the Rotterdam harbor is the ultimate dumping ground for contaminated sediment from the German and French industrial areas. In 1972, the Harbor Department of the City Public Works Administration initiated a survey into the presence of contaminants in the dredged material from the Rotterdam port area. After the initial survey the Harbor Department decided to continue the investigations by issuing a number of research contracts.

166. The samples used for the analysis of dredged material in

Table 11

Contaminants Content of Sediment in European Harbors*

| Harbor and Country | Zinc | Copper | Chromium | Lead | Cadmium | Nickel | Mercury | Tin | Iron | Arsenic | Antimory | Beryllium | $TiO_2$ | NaCl | Hydrocarbons | Total Organic Chlorides | Oil |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Belgium, Antwerp Harbor | <425 | 87 | 99 | 88 | 6.8 | ** | | ** | | ** | < 35 | ** | | | | | |
| France, Bordeaux | | | | | | | | | | | | | | | | | |
| Dordogue River | 213 | 29 | | 117 | | 26 | | | | | | | [illegible] | [illegible] | | | |
| Garonne River | 247 | 34 | | 124 | | 28 | | | | | | | [illegible] | [illegible] | | | |
| Gironde River | 195 | 24 | | 103 | | 25 | 0.2 | | | 10 | | | [illegible] | [illegible] | | | |
| France, Dunkirk | | | | | | | | | | | | | | | | | |
| Outer Harbor | 127 | 20 | | 53 | 1 | 21 | 0.23 | | 23.230 | 8 | | | | | [illegible] | | |
| Inner Harbor | 206 | 57 | | 147 | 1 | 13 | 0.001 | | 11385 | 3 | | | | | [illegible] | | |
| Netherlands, Rotterdam | | | | | | | | | | | | | | | | | |
| Rijnhaven | 1818 | 352 | 748 | 404 | 33 | | | | | | | | | | | | |
| Masshaven | 1287 | 240 | 503 | 306 | 20 | | | | | | | | | | | | |
| Waalhaven | 1468 | 248 | 595 | 365 | 19 | | | | | | | | | | | [illegible] | [illegible] |
| Eemhaven+ | 1704 | 105 | 240 | 157 | 8 | | | | | | | | | | | [illegible] | [illegible] |
| 2e Petroleumhaven | 1144 | 178 | 346 | 246 | 14 | | | | | | | | | | | [illegible] | [illegible] |
| 1e Petroleumhaven | 917 | 160 | 309 | 191 | 13 | | | | | | | | | | | 48.0 | [illegible] |
| 3e Petroleumhaven | 707 | 104 | 255 | 151 | 10 | | | | | | | | | | | [illegible] | [illegible] |
| Botlek | 804 | 132 | 262 | 172 | 10 | | | | | | | | | | | [illegible] | [illegible] |
| Calandkanaal | 208 | 33 | 113 | 51 | 1 | | | | | | | | | | | 0.9 | 50 |
| Beerkanaal | 147 | 17 | 83 | 40 | 1 | | | | | | | | | | | 0.5 | 50 |
| Great Britian, Liverpool | | | | | | | | | | | | | | | | | |
| Liverpool Docks | 200 | 60 | 22 | 150 | 1.4 | | 2++ | | | | | | | | | | |
| Mersey River | 400 | 120 | 48 | 900 | 2 | | 1++ | | | | | | | | | | |

* Expressed in parts per million dry weight.
** The amounts were lower than the detection limit.
\+ Relatively low concentrations of heavy metals may be due to dredging operations just before sampling.
\++ ppm of wet weight.

Rotterdam were collected from the river and the harbor basins before commencement of the actual dredging. For the sampling, a small-size grab was used that had a capacity of about 1.5 ℓ. In total, 140 samples were collected, 120 for the analysis of heavy metals and 20 for the analysis of oil and pesticides. Detailed data on contamination in Rotterdam are presented in subsequent paragraphs.

## Contamination by Oil

167. The contamination of dredged material by oil is becoming a serious worldwide problem. Some aspects of oil contamination are discussed below.

### Sources and causes

168. The present economy could not exist without the large quantities of hydrocarbons mined, transported, refined, and used. Losses during these processes are virtually unavoidable. Estimates of losses vary between 0.1 and 0.5 percent. This small percentage, however, may be sufficient to cause very severe cases of pollution. The sources and causes of oil pollution are identified in Table 12. The main sources of oil in the dredged material in harbors are wastewater and leakage from refineries, leakage from ships, and discharge by the rivers.

Table 12

Sources and Causes of Oil Pollution

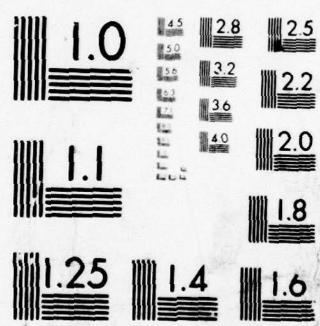
| Source | Cause |
|---|---|
| Mining | Accidents, leakage |
| Harbors | Accidents, leakage |
| Refineries | Wastewater, leakage |
| Ships | Collisions, tank cleaning, leakage etc. |
| Pipelines | Burst, leakage |
| Trucks, trains | Accidents, leakage |
| Tanks | Corrosion, burst, overfilling |
| Industrial wastewater | Leakage, imperfect treatment |
| Used oil | Dumpings (illegal) |

AD-A074 219 ADRIAAN VOLKER DREDGING CO ROTTERDAM (NETHERLANDS) F/G 13/3
ASSESSMENT OF CERTAIN EUROPEAN DREDGING PRACTICES AND DREDGED M--ETC(U)
DEC 78 K D'ANGREMOND, J BRAKEL, A J HOEKSTRA DAJA37-75-C-0382

UNCLASSIFIED WES-TR-D-78-58 NL

2 OF 3

AD
A074219




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

## Chemical composition

169. Oil consists mainly of a mixture of a large number of hydrocarbons, but other chemical combinations also are present. Knowledge of the chemical composition of oil is required in connection with the possible effects of the components in polluted dredged material. If oil is analyzed, attention should be paid to the following components and additives:

- a. Hydrocarbons
  - (1) Aliphatic
  - (2) Cyclic Aliphatic
  - (3) Aromatic (lower and polycyclic)
  - (4) Olefins
  - (5) Alkynes
- b. Naphta acids (emulgating)
- c. Phenols (taste)
- d. Thiophenols } smell
- e. Mercaptans } smell
- f. Sulfones } aggressive
- g. Sulfur } aggressive
- h. Cyanides
- i. Lead and lead combinations } toxic
- j. Polychlorinated biphenyls (PCB's) } toxic

## Measuring methods

170. For the measurement of oil pollution, attention is often focused on the hydrocarbon fraction or subfractions. Sometimes other fractions are analyzed as well, especially if toxic components are expected or if the source of the oil has to be determined. For this type of analysis, special methods are available. Because of the complex composition of oil, a sample from a given spill can be "fingerprinted," i.e., identified precisely and assigned to the ship from which it was spilled. For the analysis, both manual and automatic methods are used. The manual methods can indicate the kind, source, and quantity on an occasional basis; whereas the automatic methods are generally used to monitor continuously the quality of wastewater, surface water, and

drinking water. Based on the experience gained so far in The Netherlands, dredged material is preferably analyzed by means of the infrared spectral analysis.

Oil content of dredged material from the Rotterdam Harbor

171. Table 13 gives the results of the analysis of dredged material sampled in 1972 and 1974. It is evident that the contamination was considerably less in 1974.

Table 13

Oil Contents of Rotterdam Harbor Sediments in 1972 and 1974

| | Oil Content, mg/kg (Dry Weight) | | | | | |
|---|---|---|---|---|---|---|
| | Maximum | | Average | | Minimum | |
| Location | 1972 | 1974 | 1972 | 1974 | 1972 | 1974 |
| Waalhaven | 330 | 35 | 275 | 35 | 220 | 35 |
| Eemhaven | 320 | 20 | 285 | 20 | 250 | 20 |
| 2e Petroleumhaven | 540 | 795 | 485 | 295 | 390 | 30 |
| 1e Petroleumhaven | 1850 | 685 | 1275 | 360 | 740 | 45 |
| 3e Petroleumhaven | 510 | 75 | 265 | 35 | 110 | 10 |
| Botlek | 230 | 10 | 165 | 10 | 100 | 10 |
| Calandkanaal | 50 | 10 | 50 | 10 | 50 | 10 |
| Beerkanaal | 50 | 10 | 50 | 10 | 50 | 10 |

## Contamination by Heavy Metals

172. This part of the report will give details of the origin of the heavy metals found in the harbor mud in Rotterdam. Results of measuring programs in 1972 and 1974 are presented. Research on the behavior of heavy metals is concentrated at the Institute of Soil Fertility at Haaren and the Delft Hydraulics Laboratory.

Heavy metals in the Rhine River

173. The Rhine River is often described as the sewer pipe of Europe because of the enormous quantities of industrial wastes discharged into it. Heavy metals form an important part of these waters. The

larger part of the discharge of heavy metals is bound to the silt load of the river. A 1970 study of silt movement in the southern part of the North Sea used heavy metal content as an indicator of the origin of the sediment. It was found that the heavy metal content of the sediments from several rivers varied considerably (Table 14). The differences in heavy metal content in the rivers cannot be attributed only to industrial activities in the respective catchment areas; the geochemical characteristics of the catchment areas are also different. The heavy metal discharge of the Rhine is not constant, as shown by several measurements not presented herein.

Table 14

Comparison of Heavy Metals Contents in Sediments of Four Important Rivers in Western Europe

| | Heavy Metal Content, ppm (Dry Weight)* | | | |
|---|---|---|---|---|
| Element | Rhine | Meuse | Scheldt | Eems |
| Zinc | 2900 | 2500 | 800 | 1100 |
| Chromium | 1240 | 620 | 380 | 180 |
| Copper | 600 | 340 | 140 | 160 |
| Nickel | 100 | 83 | 53 | 79 |
| Lead | 800 | 600 | -- | -- |
| Cadmium | 45 | 45 | -- | -- |
| Mercury | 23 | -- | -- | -- |
| Arsenic | 220 | -- | -- | -- |
| Antimony | 18 | -- | -- | -- |

* Extrapolated to 100 percent of the fraction <16 μ.

174. The heavy metal contents presented in Table 14 are standardized to the fraction of the sediment that is less than 16 μ in size because of the strong relationship between the heavy metal content and the grain-size distribution of the sediment. Apparently the finer particles show a greater adhering capacity as a result of the larger specific area. A linear relationship has been shown between the percentage of fines (<16 μ) in the sediment and the content of heavy metals, valid

for a given location in the river basin. The table gives the contents upstream of the tidal zone, except for the Scheldt River.

175. In the nontidal zone of a river basin, many of the metals are bound to the suspended silt. Although the average concentration of silt in the Rhine water is as low as 45 ppm, $1.8 \times 10^6$ kg of lead is discharged annually attached to the silt and only $0.7 \times 10^6$ kg in solution.

Distribution of heavy
metals in the Dutch delta region

176. Heavy metals appear in considerably lower concentrations in harbor mud than in Rhine mud. Moreover, the mud contains decreasing amounts of heavy metals as it approaches the sea. From studies of de Groot and others,[13,14] it appears that after passing the freshwater tidal zone, a number of metals are mobilized and go into solution as metal-organic compounds. One of the causes of this process is the disintegration of the organic components in the tidal area between the freshwater tidal zone and the sea. If there is no tidal movement, this process does not occur. This is clearly illustrated in Figure 41 (taken from the studies of de Groot), which gives the qualitative contents of various metals in sedimented silt in the Rhine delta and the Scheldt and Eems Rivers. On the righthand side, the original contamination upstream is shown and on the lefthand side, the much lower concentration in the seaward part of the delta. When reading Figure 41 it should be realized that a small part of the discharge of the Rhine drains into the IJssel Lake, where tidal movement has been eliminated since 1932 (Ketelmeer). Further, there is an open connection from the Rhine to the North Sea through the Rotterdam Harbor. In this area the silt is subject to the same tidal phenomena as elsewhere in the estuary. As such, the decrease of the heavy metal content from east to west in the harbor area is quite normal. From the latest investigations de Groot and his colleagues concluded that the low content of heavy metals in the western part of the harbor area is not only due to mobilization, but also partly due to an influx of clean silt from the North Sea. A special contribution by de Groot on the subject of heavy metal contamination is added as Appendix G.

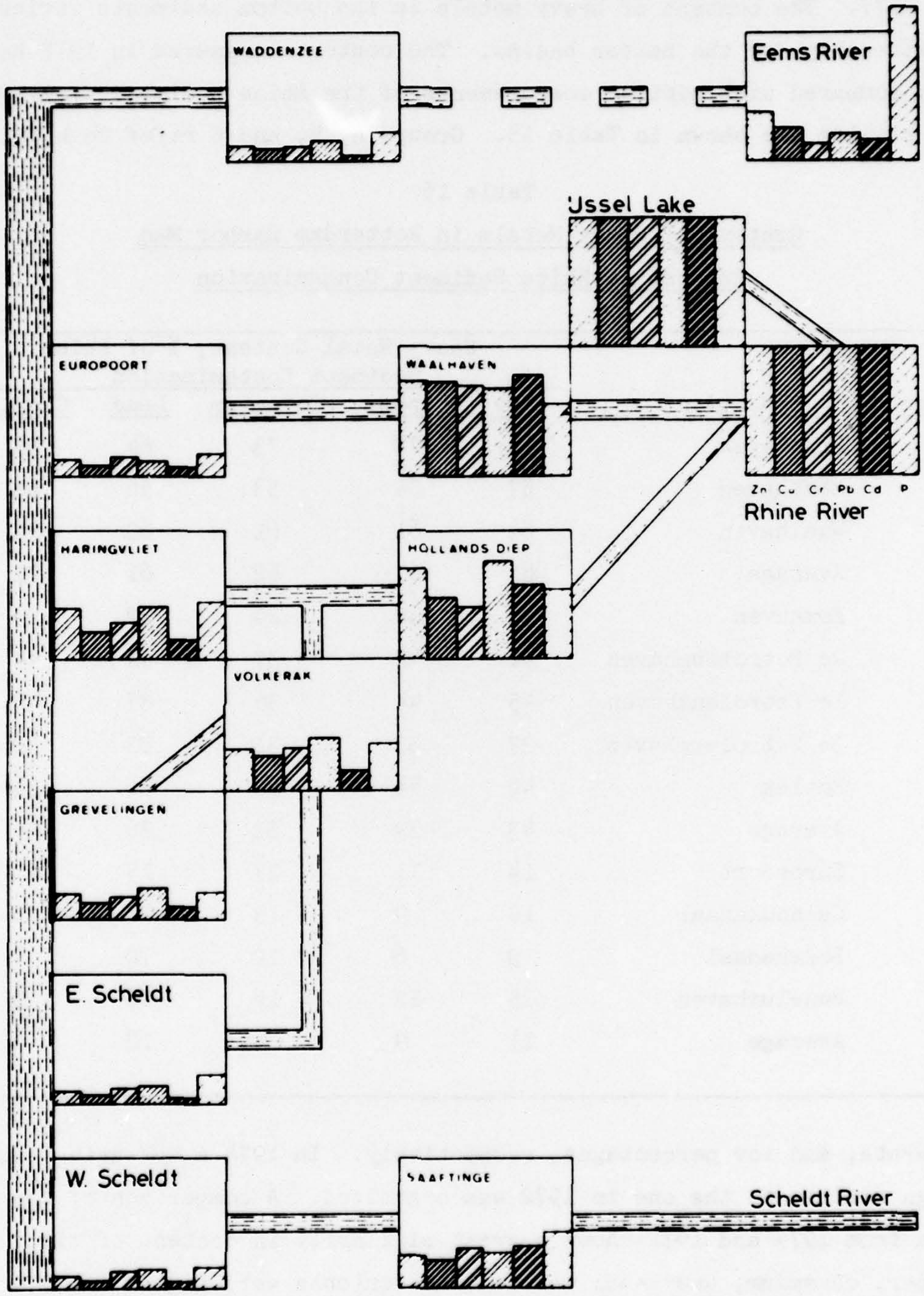



Figure 41. Distribution of heavy metals in the Dutch delta

Heavy metals in Rotterdam Harbor

177. The content of heavy metals in the bottom sediments varies considerably for the harbor basins. The contents measured in 1972 have been compared with similar measurements of the Rhine sediment from 1970; the results are shown in Table 15. Groups A, B, and C refer to high,

Table 15

Content of Heavy Metals in Rotterdam Harbor Mud Related to Rhine Sediment Contamination

| Group | Location | Heavy Metal Content, % of Rhine Sediment Contamination | | | | |
|---|---|---|---|---|---|---|
| | | Zinc | Copper | Chromium | Lead | Cadmium |
| A | Rijnhaven | 75 | 77 | 73 | 64 | 95 |
| | Maashaven | 57 | 64 | 53 | 56 | 63 |
| | Waalhaven | 64 | 61 | 61 | 63 | 56 |
| | Average | 65 | 67 | 62 | 61 | 71 |
| B | Eemhaven | 35 | 30 | 29 | 32 | 29 |
| | 2e Petroleumhaven | 51 | 42 | 37 | 42 | 44 |
| | 1e Petroleumhaven | 45 | 44 | 36 | 37 | 46 |
| | 3e Petroleumhaven | 37 | 33 | 31 | 33 | 40 |
| | Botlek | 42 | 44 | 32 | 36 | 34 |
| | Average | 43 | 39 | 33 | 36 | 39 |
| C | Europoort | 14 | 11 | 17 | 15 | 10 |
| | Calandkanaal | 10 | 9 | 13 | 10 | 5 |
| | Beerkanaal | 9 | 6 | 12 | 10 | 4 |
| | Beneluxhaven | 15 | 13 | 16 | 16 | 9 |
| | Average | 11 | 9 | 14 | 12 | 6 |

moderate, and low percentages, respectively. In 1974 a measuring campaign similar to the one in 1972 was organized. A comparison of the data from 1974 and 1972 shows a great similarity in content of zinc, copper, chromium, and lead; the cadmium contents were higher in 1974 than in 1972. A short survey of the composition of the Rhine sediments further upstream also showed that the content of cadmium had increased

more than for any other important element. The detailed results of the analysis of harbor mud in 1972 and 1974 are given in Appendix H.

## Contamination by Pesticides and Biocides

178. Measurement of contamination of dredged material by pesticides was required for environmental investigations. The effects of pesticides on disposal areas are under special study now; the results are not available. In 1972 and 1974 the bottom material of the Rotterdam Harbor was sampled and analyzed; the results are given in this section.

### Specification

179. The common abbreviations and full names of pesticides and biocides measured are listed below:

a. HCB = hexachlorbenzeen.

b. BHC = benzeenhexachloride.

c. HEPO = heptachloorepoxyde.

d. Diel = dieldrin.

e. DDD = dichloordiphenyldichloorethane.

f. DDE = dichloordiphenyldichloorethane.

g. DDT = dichloordiphenyltrichloorethane.

h. DDE and DDD are metabolites of the insecticide DDT. The contents of the insecticides heptachloor, aldrin, endrin, and DDT were lower than the detection limit (<0.01 ppm). Also the total amount of organic chlorides, which gives an indication of the total chemical contamination, was measured.

### Degree of pollution

180. Table 16 gives the results of the analyses of dredged material sampled in 1972.

181. The results of the analysis of the dredged material sampled in 1974 are given in Table 17.

### Summary

182. The total amount of organic chlorides, which gives an indication of the total chemical contamination of the Rotterdam harbor, is comparable with the contents found in the Rhine River. An exception is

Table 16

Quantity of Pesticides and Total Amount of Organic Chlorides in Dredged Material in Rotterdam Harbor (1972)

| Place | Quantity Dry Material Percent | Pesticides, ppm | | | | | | | | Total Amount of Organic Chlorides |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | BHC | | | | | | | |
| | | HCB | α | β | γ | HEPO | Dieldrin | DDE | DDD | |
| Waalhaven | 28 | 0.18 | 0.07 | 0.11 | 0.04 | 0.18 | 0.25 | -- | -- | 6.4 |
| | 59 | -- | -- | -- | -- | 0.20 | -- | 0.12 | -- | 1.9 |
| Eemhaven | 42 | -- | -- | -- | -- | 0.14 | -- | -- | -- | 3.6 |
| | 43 | -- | -- | -- | -- | 0.12 | 0.14 | -- | -- | 2.1 |
| 2e Petroleumhaven | 36 | -- | -- | -- | -- | 0.06 | 0.08 | -- | -- | 4.5 |
| | 29 | -- | -- | -- | -- | 0.17 | 0.24 | -- | -- | 7.2 |
| | 32 | 0.12 | -- | -- | -- | 0.09 | 0.25 | -- | -- | 7.2 |
| 1e Petroleumhaven | 45 | -- | -- | -- | -- | 0.13 | -- | 0.07 | -- | 4.9 |
| | 49 | 0.26 | 0.14 | -- | -- | 0.18 | -- | 0.47 | -- | 18.0 |
| | 29 | 1.15 | 1.00 | 1.04 | -- | 0.28 | 1.56 | -- | 0.62 | 121.0 |
| 3e Petroleumhaven | 40 | 0.10 | -- | -- | -- | 0.33 | -- | -- | -- | 2.5 |
| | 43 | -- | -- | -- | -- | 0.24 | 0.16 | -- | -- | 2.1 |
| | 30 | 0.02 | 0.02 | -- | -- | 0.36 | 0.23 | 0.13 | -- | 3.9 |
| Botlek | 35 | 0.14 | -- | -- | -- | 0.26 | -- | -- | -- | 3.1 |
| | 36 | 0.08 | -- | -- | -- | 0.14 | -- | -- | -- | 2.8 |
| Calandkanaal | 33 | -- | -- | -- | -- | 0.57 | 0.09 | -- | -- | 1.8 |
| | 36 | -- | -- | -- | -- | 0.25 | 0.20 | 0.14 | -- | 0.8 |
| | 52 | -- | -- | -- | -- | 0.37 | 0.14 | 0.74 | -- | 0.6 |
| | 49 | -- | -- | -- | -- | 0.06 | 0.08 | -- | -- | 0.6 |
| Beerkanaal | 61 | 0.10 | -- | -- | -- | 0.15 | -- | 0.15 | -- | 0.5 |

Table 17

Quantity of Pesticides and Total Amount of Organic Chlorides in Dredged Material in Rotterdam Harbor (1974)

| Place | Quantity Dry Material Percent | Pesticides, ppm p,p' DDE | TDE (p,p' DDD) | Dieldrin | HCB | Total Amount of Organic Chlorides |
|---|---|---|---|---|---|---|
| Waalhaven | 52 | * | * | 0.02 | -- | 2.0 |
| Eemhaven | 47 | | | 0.02 | 0.04 | 2.1 |
| 2e Petroleumhaven | 32 | | | 0.02 | 0.22 | 14.3 |
| | 34 | | | 0.02 | 0.06 | 35.8 |
| | 25 | | | 0.02 | 0.20 | 32.4 |
| | 24 | | | 0.02 | 0.34 | 51.1 |
| 1e Petroleumhaven | 29 | | | 0.56 | 0.14 | 15.4 |
| | 37 | | | 0.94 | 0.38 | 42.9 |
| | 42 | | | 0.02 | 0.12 | 36.1 |
| | 30 | | | 0.02 | 1.14 | 318.0 |
| | 25 | | | 0.02 | 1.10 | 669.0 |
| 3e Petroleumhaven | 47 | | | 0.04 | 0.04 | 13.9 |
| | 34 | | | 0.09 | 0.96 | 10.5 |
| | 37 | | | 0.05 | 0.08 | 9.2 |
| Botlek | 28 | | | 0.02 | 0.07 | 2.0 |
| | 32 | | | 0.06 | 0.06 | 12.2 |
| Calandkanaal | 24 | | | 0.03 | 0.02 | 2.0 |
| | 52 | | | 0.02 | 0.02 | 2.0 |
| Beerkanaal | 75 | | | 0.02 | 0.02 | 2.0 |
| River KMR 1010 | 33 | | | 0.09 | 0.18 | 14.7 |
| | 38 | | | 0.02 | 0.09 | 11.8 |
| | 44 | | | 0.02 | 0.07 | 6.2 |
| River near Botlek | 67 | | | 0.03 | 0.02 | 2.0 |
| | 52 | | | 0.02 | 0.08 | 2.3 |
| | 58 | | | 0.02 | 0.02 | 2.2 |
| River KMR 1021 | 67 | | | 0.02 | 0.02 | 2.0 |
| | 60 | | | 0.02 | 0.02 | 2.0 |
| | 71 | | | 0.02 | 0.03 | 2.0 |
| River near Europoort | 33 | | | 0.02 | 0.03 | 2.0 |
| | 37 | | | 0.02 | 0.02 | 2.0 |
| Sea (harbour disposal) | 79 | | | 0.02 | 0.02 | 2.0 |
| Sea (river disposal) | 70 | | | 0.02 | 0.02 | 2.0 |

* The amounts are lower than the detection limit.

the mud in the le Petroleumhaven, which must be a local contamination.

183. Pesticides and biocides form only a small part of the organic chlorides. They occur in quantities that could be expected from the contamination in Rhine water. In the seaward area (Europoort), however, concentrations are very low, due to the fact that in this harbor the siltation is of marine origin.

## Contamination by Salt

### Salt intrusion

184. Only in Holland was salt intrusion found to be a major cause of concern in disposal operations. This must be attributed to the fact that the farmlands are in the western part of the country situated at an elevation below mean sea level.

185. The dredging process in the Rotterdam Harbor creates an increased salt intrusion into the agricultural lands in two ways. In the first place, deepening of the Nieuwe Waterweg in the past has certainly contributed to a further intrusion of the salt wedge into the river. In this way inlets, which could be used in the past to replenish or flush polder waters, cannot be used at present. In the second place, disposal of dredged material along with brackish water in land-based disposal areas creates the risk of a gradual seepage of this brackish water into the surrounding ground or surface waters. This is the main reason that no unconfined disposal areas are used. There is a third possibility of salt intrusion along with dredged material. Because sand is getting scarce for construction material, projects have been developed to dredge sand at sea for the building industry and to sell it on a commercial basis. This sand also contains water with a high salinity.

### Salinity limits

186. Acceptable salinity of the inland waters is determined by considering the production loss in the agricultural sector and the taste limits in connection with the production of drinking water. In general, a salt content of 300 mg/$\ell$ Cl is considered to be a maximum limit for the inland waters. Insofar as the intrusion of the salt wedge in the

Nieuwe Waterweg is concerned, it has been decided to reduce the depth of certain sections to create obstructions to the wedge. A reduction of the depth is possible from a nautical point of view because the deep-draft vessels are generally handled in the western part of the harbor area. Salt intrusion due to the operation of disposal areas is limited as a result of the intensive precautions taken by the authorities concerned. Salt intrusion by the importation of so-called sea-sands is also controlled by strict regulations. Since the sand delivery projects take place on a more or less industrial scale, the measures for desalinization are discussed in Part IX.

## Existing European Legislation

187. The following International Conventions are of importance regarding the environmental effects of dredging and disposal of dredged material:

- a. The Oslo Convention, 1972.
- b. The London Convention, 1972.
- c. The Paris Convention, 1974.
- d. The Helsinki Convention, 1974.

The character of the Conventions usually was regional, as mentioned below.

### The Oslo Convention

188. The Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft was held in Oslo, Norway, in February 1972. The Convention is regional for the North Sea and northeast Atlantic. The Contracting Parties pledged themselves to take all possible steps to prevent the pollution of the sea by substances liable to create hazards to human health, to harm living resources and marine life, to damage amenities, or to interfere with other legitimate uses of the sea. A Commission of the Contracting Parties was established to supervise implementation of the Convention.

189. Dumping of organohalogen and organosilicon compounds that may form such substances in the marine environment is prohibited; excluded

are those compounds that are nontoxic, or that are rapidly converted in the sea into biologically harmless substances. Wastes containing significant quantities of the following substances require a specific permit to dump: arsenic, lead, copper, zinc, and their compounds; and cyanides and pesticides, and their by-products. No quantitative standards are available.

The London Convention

190. The Convention for the Prevention of Marine Pollution by Dumping of Wastes and Other Matter was held in London, England, in November 1972. The Convention affects all oceans and seas. The Contracting Parties agreed individually and collectively to promote the effective control of all sources of pollution of the marine environment and take effective measures individually, according to their scientific, technical, and economic capabilities, and collectively to prevent marine pollution caused by dumping.

191. Dumping of the following substances is prohibited:

a. Organohalogen compounds.

b. Mercury and its compounds.

c. Cadmium and its compounds.

d. Persistent plastics and other persistent synthetic materials that may float or remain in suspension so as to interfere materially with fishing, navigation, or other legitimate uses of the sea.

e. Crude oil, fuel oil, heavy diesel oil, lubricating oil, hydraulic fluid, or any mixtures of these.

f. High-level radioactive wastes or other high-level radioactive matter defined as unsuitable for dumping at sea.

The prohibition does not apply to wastes or other materials containing the materials mentioned above as trace contaminants. Prior special permits are required for dumping significant amounts of waste containing arsenic, lead, copper, zinc, organosilicon compounds, cyanides, fluorides, pesticides, or their by-products not covered by the prohibition list. No quantitative standards are available.

The Paris Convention

192. The Convention for the Prevention of Marine Pollution from

Land-Based Sources was held in Paris, France, in February 1974. This Convention is a regional one affecting a maritime area that embraces the North Sea, the English Channel, the Irish Sea, and a considerable part of the Atlantic and Arctic Oceans, as well as inland waters extending to the freshwater limit. Pollution from land-based sources is defined as the pollution of the maritime area by material from the coast including submarine channels and other channels and by material from artificial structures. A commission of representatives of the Contracting Parties is to be set up to oversee the workings of the Convention generally, monitor the environment in the maritime zone, and receive and disseminate information.

193. The aim of the Convention is the elimination of organohalogen compounds and those that could give rise to such compounds in the marine environment, but excluded those compounds biologically harmless or that rapidly break down in the sea into harmless biological substances. Mercury and its compounds, cadmium and its compounds, persistent synthetic materials and oils, and persistent hydrocarbons also are mentioned as prohibited for dumping. Strict limitation is given to organic compounds of phosphorus silicon, tin, and those materials that could give rise to such compounds in the marine environment; excluded are those that are biologically harmless, or rapidly become so, phosphorus, nonpersistent oils, petroleum products, arsenic, chromium, copper, lead, nickel, zinc, and their compounds.

The Helsinki Convention

194. The Convention for the Protection of the Marine Environment of the Baltic Sea Area was held at Helsinki, Finland, in March 1974. It applies to the Baltic Sea proper, the Gulf of Bothnia, the Gulf of Finland, and the entrance to the Baltic Sea. The Contracting Parties will individually or jointly take all appropriate legislative, administrative, or other relevant measures, in order to prevent and abate pollution and to protect and enhance the marine environment of the Baltic Sea area.

195. The aim of the Convention is to counteract the introduction of hazardous substances such as DDT (and its derivatives, DDE and DDD)

and PCB's. Substances and materials strictly to be limited and not introduced into the Baltic Sea without prior special permit are mercury, cadmium, antimony, arsenic, beryllium, chromium, copper, lead, molybdenum, nickel, selenium, tin, vanadium, zinc, and their compounds, elemental phosphorus, phenols and derivatives, phthalic acid and derivatives, cyanides, persistent halogenated hydrocarbons, polycyclic aromatic hydrocarbons and derivatives, persistent toxic organosiliconic compounds, persistent pesticides, herbicides, timber and hides preservatives, radioactive materials, acids, alkalies, surface active agents in high concentrations, oil and petrochemical wastes, substances having adverse effects on taste and/or smell, and materials that may interfere with any legitimate use of the sea. Annex V of the Convention states that the prohibition of dumping shall not apply to the disposal at sea of dredged material provided that it does not contain significant quantities and concentrations of the prohibited substances.

Ratifying countries

196. Table 18 gives the European countries that ratified the most important conventions.

National legislation

197. Most European countries are preparing or adapting their national legislation on surface and seawater pollution in accordance with the Oslo, London, and Paris Conventions. The quantitative standards related to this legislation are the subject of an intensive discussion among scientists from various disciplines, ranging from public health experts to economists. It is premature to mention any of the proposed figures in this report because the figures change very considerably from day to day.

Table 18

Ratifying Countries for Conventions

| Countries | Conventions | | | |
|---|---|---|---|---|
| | Oslo 1972 | London 1972 | Paris 1974 | Helsinki 1974 |
| Belgium | X | | X | |
| Denmark | X | X | X | X |
| Federal Republic of Germany | X | | X | X |
| Finland | X | | | X |
| France | X | | X | |
| German Democratic Republic | | | | X |
| Iceland | X | X | | |
| Ireland | X | | X | |
| Luxembourg | | | X | |
| Netherlands | X | | X | |
| Norway | X | X | X | |
| Poland | | | | X |
| Portugal | X | | X | |
| Spain | X | X | X | |
| Sweden | X | X | X | X |
| United Kingdom | X | X | X | |
| USSR | | X | | X |

## PART IX: ENVIRONMENTAL EFFECTS

### Turbidity

198. Turbidity is often increased by dredging operations due to the fact that soil particles are stirred up and come into suspension. The coarser particles will settle rapidly, but the finer particles remain in suspension for a longer time. These finer particles may be transported over long distances as a result of their small fall velocity in comparison to the prevailing current velocities. Because the fall velocity is of decisive importance, it seems worthwhile to make two observations:

- a. The fall velocity of clay and silt particles is strongly influenced by the salinity of the surrounding water. As a result of higher salinity, the apparent grain size increases due to coagulation, which leads to a greater fall velocity.
- b. In a number of cases, the dredging process leads to the discharge of a mixture of relatively high solids concentration. In general, the settling velocity of the mixture follows the character of density currents rather than that of individually falling particles. The fall velocity of a density current is greater than the one calculated on the basis of individual particles. This effect is responsible for disappointing results of agitation dredging.

#### Effects of turbidity

199. The effects of an increased amount of suspended material on the environment can be placed into two categories:

- a. Reduction of light penetration, which is actually turbidity.
- b. Covering of certain areas with a layer of dredged material.

These two effects are significant only when the natural clarity of the water is great and when the covered areas have rich flora and fauna. Neither case applies to the Rotterdam area because the natural turbidity is high and, as a reuslt of the large masses of bottom material transported by the tidal and river currents, there is hardly any flora

available. As to the fauna, only those species are present that can survive deposition of the large natural sand transport. The geological setting is such that recent sediments are prevalent to a great depth in the country and in the southern part of the North Sea. Therefore, there is a great similarity between the dredged material disposed of and the natural sand transported as a result of tidal and river currents. This also reduces adverse effects of dredge-induced turbidity.

200. Research on these aspects is being performed by two research institutes in The Netherlands, The Netherlands Institute of Sea Research at Texel and The Netherlands Institute of Fisheries Research (RIVO) at IJmuiden. The investigations of both institutes reveal the impossibility of making generally applicable statements on the effect of dredging and turbidity. It appears that the effect of any dredging or disposal operation depends on both the local conditions and the kind of operation. In this respect, the southern part of the North Sea is considered to be typical due to a high natural turbidity and a great mobility of bottom material and bottom fauna. Most of the work of RIVO is done in consultation with the International Council for the Exploration of the Sea (ICES), in which many research institutes from Europe have joined their forces. For the purposes of the present report, the reader is referred to ICES Publication No. 46, which deals with the effect of dredging operations on fishing.[15]

201. Lately, additional effects of suspended dredged material have attracted attention. These effects are due to the fact that the finer sediments are often the carriers of contamination. So far, little is known about the effects of suspending contaminated material, and the following points have the character of questions:

- a. Is it more harmful to leave contaminated silt on the bottom of a river or sea or to dredge and transport this silt to a confined disposal area?
- b. What happens to the contaminants if contaminated material, once settled, is resuspended? (This may also happen as a result of natural conditions.) If, as a result of the resuspension, the contaminants are mobilized and get into solution, is this worse than a continued adhesion to the sediments?

It is clear that answering these questions will take long research. Probably this research program will be sponsored by Rijkswaterstaat, Directie Noordzee.

Bubble screens

202. In the Rotterdam Harbor area no measures are taken to control or curb dredge-induced turbidity. Another but similar problem, the reduction of silt penetration into harbor basins, has been tackled on an experimental basis by applying a pneumatic (bubble) screen. Such a screen prevents the exchange of river water and its suspended solids content with the stagnant water in the harbor basin. In the absence of strong currents, the method could possibly also be applied to control the dispersion of dredge-induced turbidity.

Background turbidity

203. Since 1963, the sediment content of the water in the Rotterdam Harbor has been measured at regular intervals. The sediment content in milligrams per litre is determined as a function of the depth of the sample and of the phase of the tide. Figure 42 shows six examples of the variation of sediment content with depth. The specimens were taken at the same place in the center of the river near the Botlek at different phases (unspecified) of the tide. It is apparent from these graphs that both the average sediment content and the distribution over depth differ considerably. This variation may partly be attributable to inaccuracies in sampling and analysis, but it is mainly caused by the natural behavior of sediments in a turbulent flow. In Figure 43 the average sediment content over a vertical in the center of the river is presented as a function of the phases of the tide. The vertical distribution of sediment content is scattered. It is clear, however, that the sediment content generally increases with depth and increases rapidly near the bottom. By averaging a large number of observations, the random variations could be eliminated to a certain extent.

204. Certain locations in the river can thus be characterized. For example, data are presented in Table 19 for km 1005, 1015, and 1031 (see Figure 44 for locations) for both high and low water conditions.

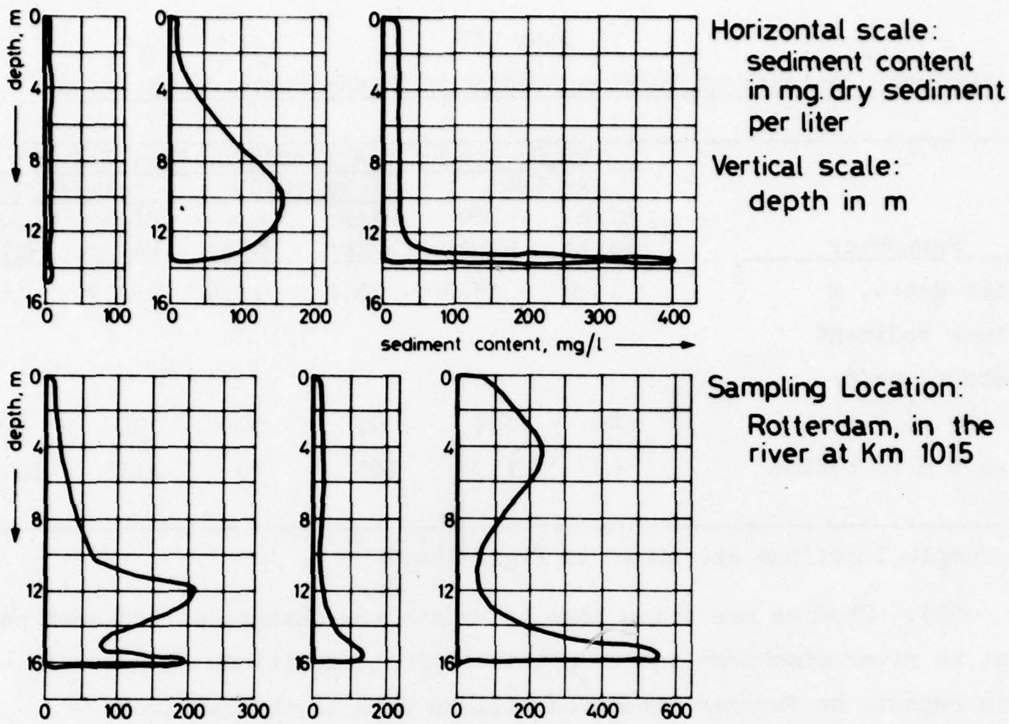



Figure 42. Examples of variation of sediment content depth at various phases of the tide

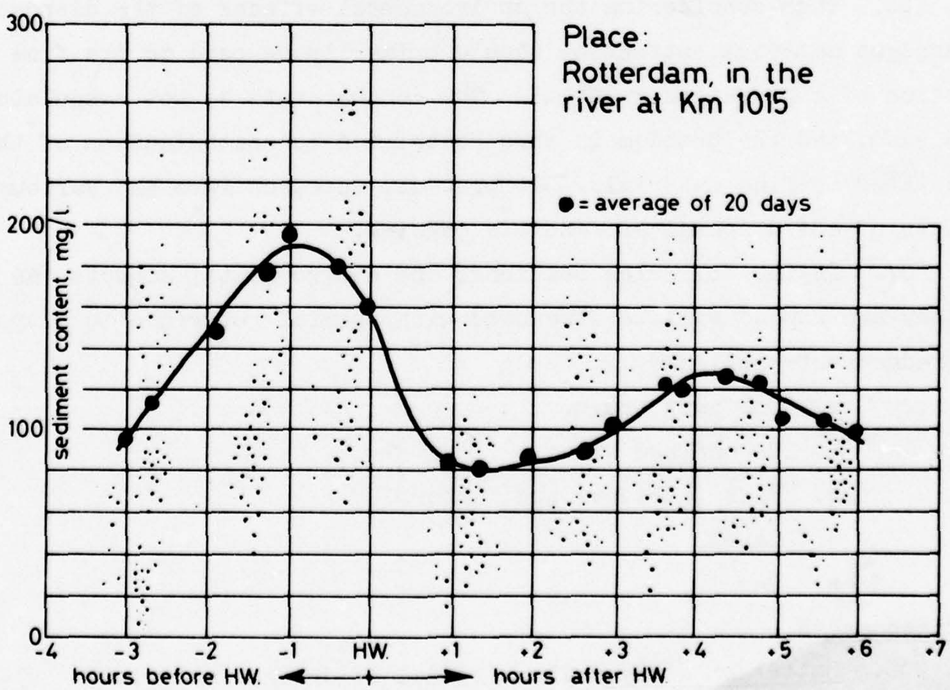



Figure 43. Average sediment content as a function of the phase of the tide

Table 19

Sediment Contents at Various Locations in the Rotterdam Waterway

| Parameter | Sample Location & Condition-Test Value* km 1005 High Water | km 1005 Low Water | km 1015 High Water | km 1015 Low Water | km 1031 High Water | km 1031 Low Water |
|---|---|---|---|---|---|---|
| Water depth, m | 14.6 | 13.0 | 16.0 | 14.4 | 17.9 | 16.3 |
| Actual sediment Content, mg/ℓ: | | | | | | |
| 0 to -6.5 m | 40 | 32 | 97 | 50 | 70 | 70 |
| -6.5 m to bottom | 60 | 53 | 165 | 70 | 115 | 107 |

* Sample locations are shown in Figure 44.

205. Studies are being done to relate the changes of sediment content to river discharge and to meteorological conditions at sea. In this report, no further attention will be paid to this subject.

## Environmental Effects of Disposal Operations

206. When considering the environmental effects of the disposal of dredged material, attention should primarily be paid to the fine fraction of the dredged material. The contaminants do not coagulate with sand, and the problem is thus restricted to contamination of the pore water of fine materials. At present, research into the various aspects of the disposal of fines is ongoing.

207. In the following sections, the environmental aspects (as far as they are known) will be discussed with special reference to disposal of dredged material in:

a. Confined areas.

b. Unconfined areas.

c. Pits in rivers and harbors.

d. Lakes.

e. Sea.

### Confined areas

208. Rotterdam study. The disposal of dredged material

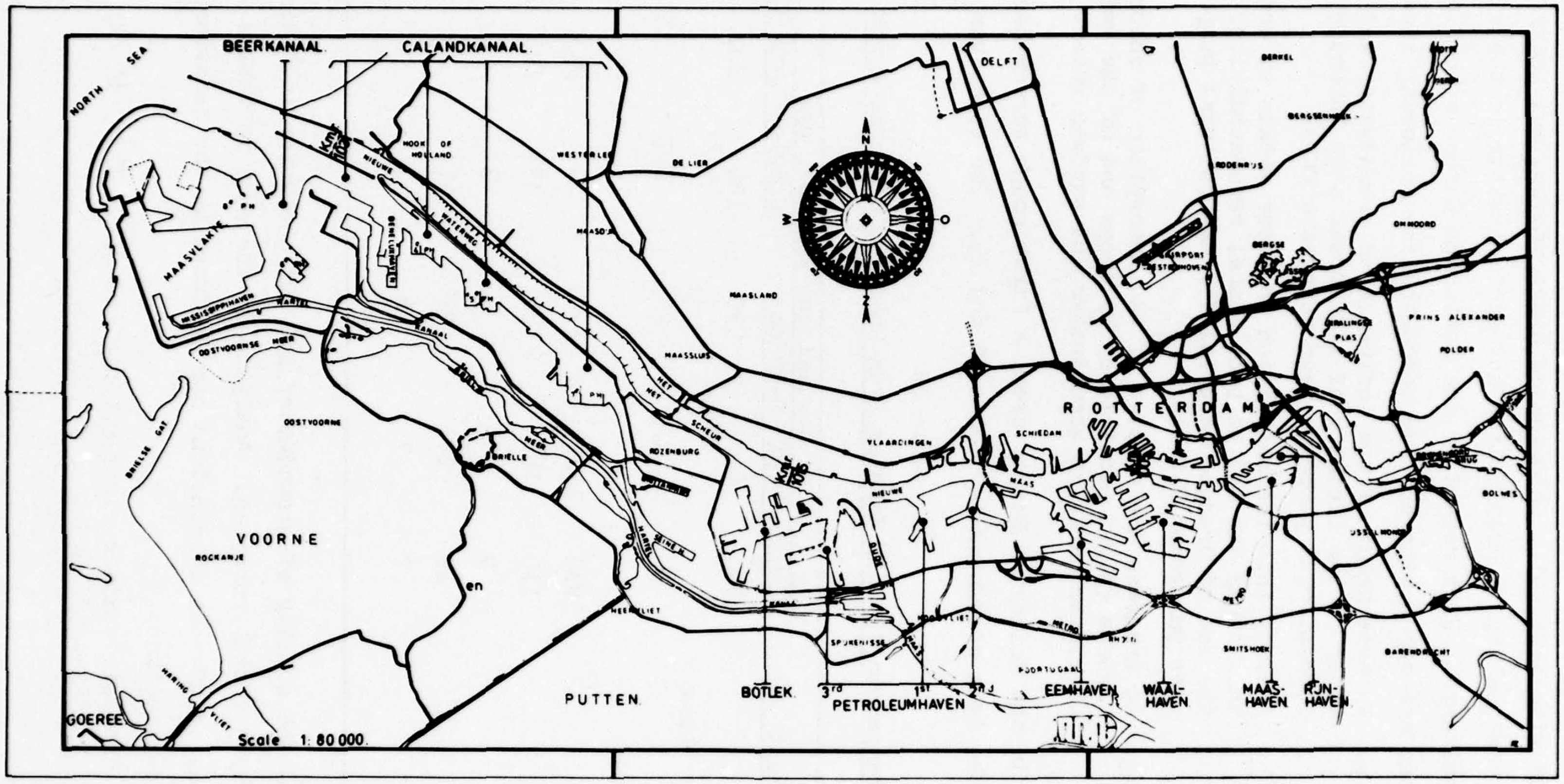



Figure 44. Sampling locations, Rotterdam

contaminated with salt, oil, chlorinated hydrocarbons, and heavy metals may affect the quality of groundwater and surface water in the vicinity of a disposal area. With regard to the Rotterdam Harbor area a number of institutes are conducting or have conducted the following studies:

- a. An assessment of the influence of groundwater and surface water in the vicinity of a disposal area intended for recreational purposes (see paragraph 209).
- b. A study into the absorption of heavy metals by crops; this study has led to provisional recommendations for the use of dredged material for agricultural purposes (see paragraph 210-214).
- c. In progress are studies of the absorption of chlorinated carbons (e.g., pesticides) by crops and of the influence of contaminants on groundwater and surface water.

209. In the Rotterdam Harbor area, a first rough survey has resulted in the data presented in Tables 20 and 21. The study was

Table 20

Contaminants in Soil Samples from Confined Disposal Areas

| Contaminant | Contaminant Content, ppm | | | | | |
|---|---|---|---|---|---|---|
| | Sample Depth 0-30 cm | | | Sample Depth 30-120 cm | | |
| Oil | 560 | 610 | 530 | 120 | 310 | 250 |
| Organically bound chloride | 74 | 2.6 | 26 | 1.7 | 1.1 | 1 |
| Heavy metals: | | | | | | |
| Zinc | 1080 | 1510 | 1250 | 710 | 955 | 925 |
| Copper | 110 | 163 | 135 | 83 | 103 | 107 |
| Mercury | 9 | 10 | 6 | 3 | 6 | 5 |
| Cobalt | 19 | 25 | 22 | 17 | 19 | 19 |
| Boron | 7 | 7 | 6 | 8 | 11 | 9 |

directed to the quality of groundwater and surface water in a disposal area for recreational purposes. Analysis of the data in Tables 20 and 21 shows that different conclusions can be drawn on the behavior of different contaminants.

210. The soil samples clearly contained oil. This oil can be

Table 21

Contaminants in Groundwater and Surface Water in the Vicinity of Confined Disposal Areas

| | Water Sampled-Contaminant Content, ppm | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Contaminant | Groundwater | | | Water from Canals | | | Deep Groundwater (Reference) | USPHS Std * |
| Oil | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | |
| Organically bound chloride: | | | | | | | | |
| Cl | $9.5 \times 10^{-3}$ | $14.7 \times 10^{-3}$ | $4.1 \times 10^{-3}$ | $11.4 \times 10^{-3}$ | $7.1 \times 10^{-3}$ | $3.5 \times 10^{-3}$ | $1.0 \times 10^{-3}$ | |
| $BOD_5$ | 13 | 5 | 3 | 1 | 3 | 1 | 1 | |
| COD | 273 | 124 | 100 | 138 | 149 | 113 | 14 | |
| Nitrogen N | | | | | | | | |
| Total | 24 | 12 | 29 | 5.3 | 7 | 10 | 46 | |
| Ammonium $NH_4$ | | | | | | | | |
| Organic | 3.2 | 2.0 | 2.8 | 1.9 | 2.9 | 2.5 | 0.5 | |
| Inorganic | 25 | 12 | 38 | 3.4 | 3.4 | 7.6 | 43 | |
| Heavy metals: | | | | | | | | |
| Zinc | <0.04 | <0.04 | <0.04 | <0.04 | <0.04 | <0.04 | <0.04 | 5.0/5.0 |
| Copper | 0.008 | 0.011 | 0.004 | 0.014 | 0.011 | 0.008 | 0.003 | 1.0/0.2 |
| Mercury | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | |
| Cobalt | <0.04 | <0.04 | <0.04 | <0.04 | <0.04 | <0.04 | <0.04 | ?/0.2 |
| Chloride | 892 | 1665 | 662 | 885 | 1500 | 594 | 956 | |

* See Reference 17.

considered as only slightly mobile because the most soluble and volatile components have disappeared by natural disintegration processes. It is not surprising that traces of oil could not be detected in the groundwater or in the surface water (see Table 21; detection limit is approximately 0.01 ppm).

211. All soil samples showed a contamination with organically bound chloride. Almost all water samples showed at least some contamination. Some of the chlorinated hydrocarbons were pesticides, which are generally strongly bound to the soil. As they are not easily soluble in water, their mobility is restricted. In 1970 Edwards[16] calculated the half-life of a number of insecticides and did not find any longer than 4 years. The half-life is determined on the one hand by the chemical stability of the compounds and on the other hand by the characteristics of the bottom sediments such as grain-size distributions, content of organic matter, moisture content, and microbiotic activities.

212. Further research of chlorinated hydrocarbons is required to assess:

- a. The influence of soil fauna (it is thought that the development of the earthworm Allobophora longa is hampered by high concentration).
- b. The absorption by plants.

Direct damage to the flora is not expected. As long as the plants concerned are not important links in the food chain, Edwards estimates hardly any adverse effects on human and animal life.[16]

213. The concentration of heavy metals in disposal areas was higher than usual in clayey soils in The Netherlands. It is remarkable that the groundwater and surface water were contaminated to a low extent only, indicating a low mobility. The last column of Table 21 shows the standards for irrigation and drinking water as given by the U. S. Public Health Service.[17] The heavy metal content of the water is below these and other standards that are applied in The Netherlands.

214. It is not expected that heavy metals will cause severe damage in the form of deficiency or toxic symptoms for plants or

animals. Two possible effects should nevertheless be mentioned: copper poisoning of sheep and manganese deficiency for vegetation. The latter effect can be adjusted by using fertilizers. For the time being, it can be concluded that the dredged material, in spite of its high content of heavy metals, can be used to reclaim areas meant for recreation, residential, and industrial purposes. The reclamation of areas for agricultural purposes, however, should be considered with the utmost care. Further results of research on the absorption of heavy metals by plants are given in paragraphs 220-225.

215. The biological oxygen demand ($BOD_5$) and the chemical oxygen demand (COD) indicate a measure for the oxygen demand of biologically disintegrating compounds and a complete oxidation of organic compounds, respectively. It appears that all of the water samples were slightly contaminated. Further, the nitrogen content of the groundwater was considerably higher than that of the surface water. Nevertheless, the COD values are no point of concern. Although the nitrogen content of the groundwater is higher than the content of the water in the ditches, the latter is of the same order of magnitude as in the polder water at a greater distance from the disposal area.

216. The salt content in the upper layers is gradually reduced by precipitation. The concentrations found in the disposal areas had an adverse and sometimes even fatal effect on earthworms.

217. Finally, it was found that confined disposal areas require a suitable system of water management, including the possibility of draining excess water and precipitation into the adjacent water bodies, from whence the fill material was dredged.

218. It was concluded that the physical properties of ripened dredged material are extremely good for vegetation. As to the chemical fertility, dredged material can even be classified among the best soils. In an experimental plantation of trees, very few died and growth and vitality were good after initial problems in the first year. Disturbances (i.e., loss of leaf color and retarded growth) were observed only in isolated locations. After a check of the heavy metal content of the leaves, there appeared to be no significant difference between

the leaves of affected and unaffected plants. Consequently, there is no reason to believe that the growth disturbances were caused by deficiencies or overdoses of certain elements.

219. The results of this first survey presented no alarming picture of the environmental effects of contaminated dredged material. It must be noted that the elements cadmium and lead, which are toxic to humans, were not taken into account.

220. Absorption of heavy metals by crops. Special investigations were done by the Institute for Soil Fertility to study the absorption of heavy metals by crops. The purpose of these investigations was to study the influence of the content of heavy metals of dredged material on the growth of plants and the degree of absorption of metals by crops. Research was conducted through tests on crops grown in pots. Investigation of eight different types of dredged material and two natural (riverine) clays as a reference comprised the test program. The following crops were used:

a. Bulbous, tuberous, or rootlike plants:
   (1) Potatoes.
   (2) Carrots.
   (3) Radishs.
   (4) Onions.

b. Leafy plants:
   (1) Lettuce.
   (2) Darnel.

c. Seed plants:
   (1) Wheat.
   (2) Dwarf beans.

221. It appeared that the yields were equal for crops from dredged material and from natural clay. An exception was wheat, which produced a smaller crop and suffered manganese deficiency when grown on dredged material.

222. The crops grown on dredged material showed a higher content of cadmium, chromium, zinc, lead, nickel, and iron and a lower content of manganese as compared to the crops grown on natural clays. For

ratios between the contents of the test crops and the reference crops, see Table 22. Fertilizing with manganese significantly reduced the

Table 22

Ratios of Heavy Metals in Crops

| Element | Ratio of Content of Test Crop to Content of Control Crop: Low | High | Average |
|---|---|---|---|
| Cadmium | 2.03 | 10.84 | 4.79 |
| Chromium | 0.98 | 15.90 | 3.85 |
| Zinc | 1.53 | 16.11 | 3.57 |
| Copper | 1.13 | 6.56 | 2.11 |
| Lead | 0.80 | 3.92 | 1.92 |
| Nickel | 0.33 | 2.85 | 1.35 |
| Iron | 0.94 | 1.41 | 1.21 |
| Manganese | 0.21 | 1.16 | 0.53 |

contents of heavy metals in the crops. A systematic relationship between the concentrations in the soil and in the crop could only be established for zinc and cadmium (Figures 45 and 46). For the other metals only incidental relationships could be found (e.g., copper, lead, and nickel in radish and grass). The results of the tests of crops grown in pots were confirmed by field surveys.

223. The high copper concentration could endanger the breeding of sheep fed with vegetation grown on such dredged material, although cattle breeding would not be affected. These effects are, however, not only encountered on disposal areas of dredged material, but similarly in the outer marshes of the Rhine, which are covered from time to time by riverine sediments with high copper concentrations.

224. The results of the investigations and the advice of the Institute of Soil Fertility have led the city council of Rotterdam to the following preliminary conclusions and recommendations for the use of dredged material:

a. Generally the amount of heavy metals in the crops is

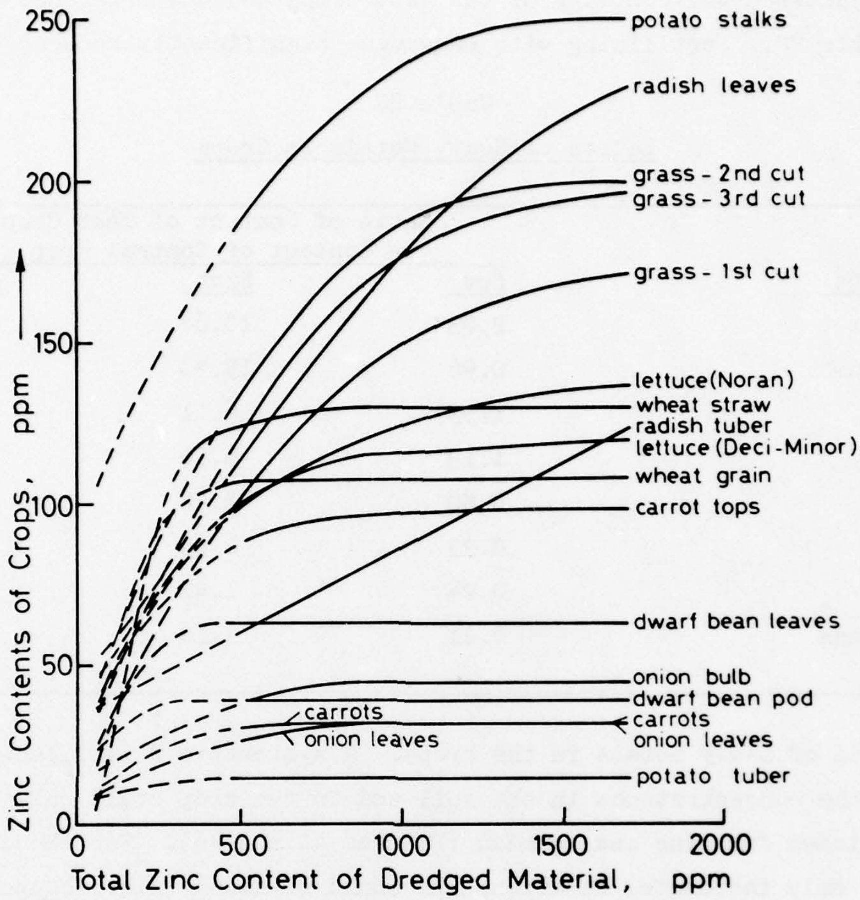



Figure 45. Relationship between the amount of total zinc in the dredged material and the amount of zinc in the crops cultivated on it

higher than usual, but not to such an extent that the health of human consumers is threatened. An exception to this is the element cadmium.

b. Dredged material disposal areas can be used for the following purposes:

(1) Residential and industrial areas.

(2) Recreation and industry.

(3) Forestry.

(4) Pastures (excluding sheep pastures).

(5) Cultivation of potatoes.

(6) Cultivation of crops like rape seed and sugar beets.

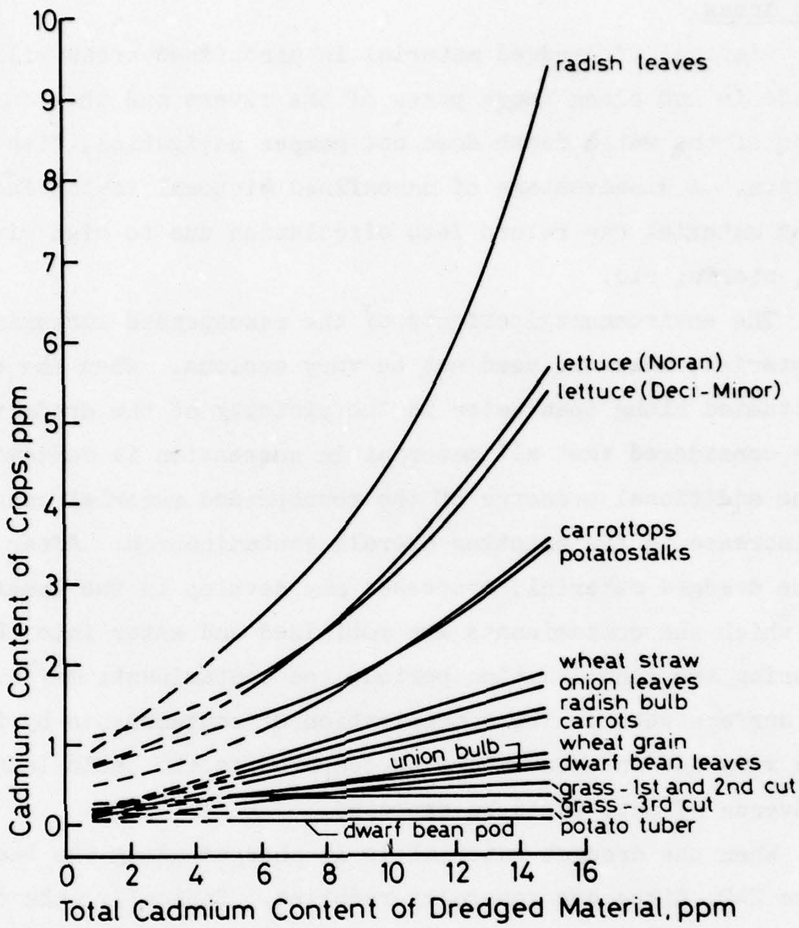



Figure 46. Relationship between the amount of total cadmium in the dredged material and the amount of cadmium in the crops cultivated on it

c. Cultivation of vegetables should not be allowed. There are too many leafy crops absorbing cadmium to a high concentration.

d. Further investigations are necessary in the concentration of cadmium in potatoes and feed for cattle (beets, maize, leaves of sugar beets, etc.).

225. Investigations are in progress on the absorption of pesticides by crops and the concentration of heavy metals and pesticides in groundwater and surface water of confined disposal areas. The absorption of heavy metals by plants can be reduced by deposition of a cover layer consisting of clean dredged material.

Unconfined areas

226. Disposal of dredged material in unconfined areas will generally be made in and along those parts of the rivers and the sea where a reduction of the water depth does not hamper navigation, fisheries, or recreation. A disadvantage of unconfined disposal is the fact that the dredged material can return into circulation due to high river discharge, storms, etc.

227. The environmental effects of the resuspended contaminated dredged material, however, need not be very serious. When the disposal area is situated along open water in the vicinity of the dredging site, it must be considered that all material in suspension is contaminated, so that the additional presence of the resuspended material causes only a slight increase in the existing overall contamination. After settlement of the dredged material, processes may develop in the anaerobic layers by which the contaminants are mobilized and enter into the pore water. During the consolidation period, the contaminants may eventually reach the surface water. The concentration of contaminants by this process is very low in open waters as compared to the basic load so that no adverse effects would be expected.

228. When the dredged material is discharged along the banks to a level above NAP, dikes are generally required. Basically, the considerations mentioned under confined disposal areas apply in that case. The water management, however, will be less complicated because all water can be drained directly into the river.

229. The objections to this method of disposal are generally of an aesthetic nature since the natural flora and fauna are disturbed. Nevertheless, in The Netherlands, vast areas have been reclaimed, on the one hand to increase the width and height of the dikes and thus to safeguard the low-lying hinterland and on the other hand to make areas of dubious value in the landscape accessible and suitable for recreation. When these elements are designed with care and fitted into the landscape, the diversification of the landscape and the facilities for recreation may be greatly enriched.

Pits

230. The storage of dredged material in deep pits within harbor basins or rivers is not considered to cause special problems, as long as the pits are located in an area where material similar to the dredged material circulates. Along natural waterways the silt would eventually settle in the pits and the effect would be the same. It should be borne in mind that by disposing of contaminated silt into a flowing river, the material is not taken out of circulation permanently and may even come into circulation again soon after high river discharges or storms.

Lakes

231. When material is discharged into pits or lakes where no contaminated sediments are present, the problems mentioned in the following paragraphs will be encountered.

232. Before a decision is made to discharge dredged material into a lake, a number of environmental conditions have to be met regarding recreation, water quality, and water management. These conditions are described in the following paragraphs.

233. Recreation. The disposal operation should be planned to prevent interference with recreational activities in most of the lake. No floating debris or oil should be apparent on the water surface. Several preventive measures are available to avoid such contamination.

- a. Discharge within screens. Either a short oil screen or a deeper screen could be used with excessive transport water pumped back into the harbor. Applying the second solution, it is possible to minimize the mixing of transport water with water of the lake.
- b. Discharge over the lake bottom under permeable or nonpermeable horizontal screens.
- c. Remove oil and debris by mechanical means, such as boats equipped to suck oil and debris from the water surface.

234. Turbidity should be minimized. This can be done either by discharging over the lake bottom or by maintaining a high concentration of solids in the discharge. The dredge plant equipment should be concealed from view. A submerged pipeline with the nozzle suspended from a pontoon could be used for transport of the dredged material. If

properly equipped, the pontoon could be used for mooring yachts. If the nozzle at the end of the delivery pipe is submerged and the dredge itself is located elsewhere, no objectionable noise will occur.

235. Water quality. Contamination of the water with heavy metals, pesticides, oil, and phosphates should be limited so that the biological and chemical quality of the water is acceptable. Measures should be taken to prevent contamination of surface water or groundwater.

a. Short-term measures. If heavy metals or pesticides originally attached to silt particles were to be released in the water column during the disposal operation, the concentration of such elements in the surface water might exceed water quality standards. This can be avoided by discharging within screens and flushing the lake regularly. Measures against contamination by oil were discussed earlier.

b. Long-term measures. Layers of dredged material can be covered with sand, uncontaminated silt, or plastic. The water of the lake could be flushed at certain intervals.

236. Water management. Changes in salinity due to dredged material disposal should be avoided in order to protect existing biological life. Also, in The Netherlands, all inland waters are used intensively for various purposes ranging from the production of drinking water to irrigation and recreation. Certain waters have to be kept fresh and others kept saline to maintain existing flora and fauna. When disposing of dredged material into a lake, the quality of water added for pipeline transport must be kept under control.

237. To prepare for the possible use of lakes (especially the OOstvoornse Meer) for disposal operations, a number of investigations have been started or are proposed. Silt and water samples have been collected. They will be analyzed by a project group specially appointed to judge the feasibility of the disposal operations. The silt samples were collected from all harbor basins. The water samples were taken in the lake and from the location where water for pipeline transport is obtained.

238. All samples were analyzed for the following characteristics:

a. Heavy metals.

b. Pesticides.

c. Oil.

d. Grain size.

e. Phosphates and sulphates.

f. Lithium, beryllium, and vanadium.

On a preliminary basis, the reaction of fish to a mixture of dredged material and water from the lake was investigated. The results are being studied at present.

239. A more extensive research program has been proposed to investigate the biological consequences of disposal in the lake. On the Maasvlakte, some fish ponds will be constructed (Figure 47). The bottom

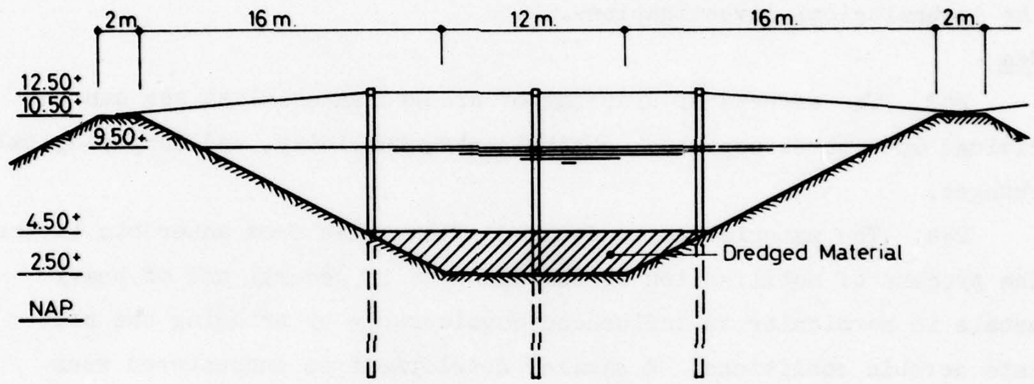



Figure 47. Fish ponds

of the ponds will consist of dredged material from several locations in the port either covered or not covered with other material. When the silt has settled, plankton from the lake will be added to feed trout, stickleback, and gudgeon, which will be placed in the ponds.

240. The Delft Hydraulics Laboratory and the Institute of Soil Fertility have been consulted about hydraulic and physicochemical problems that could occur if a lake were filled with harbor mud. An assessment was made of the processes that possibly play a role in judging the extent to which the tests in the fish ponds are representative of the prototype conditions.

241. The main subjects of the proposed research program are:

a. Elaboration and quantification of data and processes that will influence the research program.

b. Investigation of the composition of pore water in the mud

that has settled in the various harbor basins.

c. Investigation of the behavior of heavy metals in the sediment, the groundwater, and the water of the fish pond.

d. Laboratory tests of the behavior of heavy metals that migrate from the groundwater into the surface water.

242. In addition to the biological investigations, a number of technological investigations are proposed such as the increase of the concentration of dredged material in slurry mixtures, the spreading of disposed silt, the water balance, etc. A decision has to be made to determine whether the biological research program will be affected by the technological investigations.

Sea

243. The effects of disposal of dredged material at sea can be divided into three aspects: contaminants, turbidity, and morphological changes.

244. The material to be dredged often comes from anaerobic layers. The process of mobilization of contaminants in general and of heavy metals in particular is influenced considerably by bringing the silt into aerobic conditions. A similar development is encountered when dredged material is dumped at sea and increased concentrations of heavy metals may occur in the seawater. Soluble heavy metals are a potential source of pollution of the marine environment.

245. In The Netherlands an extensive research program has recently been commissioned by Rijkswaterstaat to study what influence the disposal of dredged material at sea will have on the quality of the seawater. These investigations concern the effects on organisms of absorption or accumulation of contaminants present either in seawater or in suspended or settled silt. At the same time an indication must be obtained on the extent of the area influenced by this contaminated seawater and/or suspended silt.

246. The large quantities of dredged material that are discharged at a dump site and that consist partly of fine sand and partly of silt lose the largest part of their fines during the disposal operations. The silt remains in suspension and causes a temporary high degree of

turbidity around the dump site. The high turbidity in turn causes a reduction of the light penetration. Although no special attention has been paid to this aspect, it need not be considered harmful because the photosynthetic processes in the eutrophic seawater are retarded, and the chances of an excessive plankton production are reduced. Further, it can be mentioned again that the presence of suspended silt near the mouths of the Rhine River is by no means an unnatural phenomenon. This view is supported by the harbor authorities of Le Havre, Rouen, Bordeaux, and Marseille.

247. It is not yet possible to give a definite answer to the question of whether and to what extent the disposal of silt at sea affects the recreational use of the beaches and coastal waters. This aspect is currently being analyzed.

248. Another possibly very negative effect of the discharging of dredged material is the supposition that silt from the disposal site contributes considerably to the periodical heavy siltation of the harbor entrances. The validity of this supposition will be tested further with the aid of field surveys, mathematical calculations, and silt balance studies.

Disposal of sand

249. The above considerations are all based on the fact that most of the dredged material from maintenance dredging is silty material. However, sandy soils also are frequently dredged from approach channels and from the deepening of harbor basins. This material is given a useful purpose, either for raising the level of areas for industry, town extensions, and road foundations or for strengthening the shore.

250. The environmental consequences of the use of sand for beach nourishment purposes are negligible because natural material is used. For the other purposes, only the salt content of the material may play a role. Countermeasures are discussed in relevant sections of this report.

## Limits for Soil Pollution by Heavy Metals

251. The lower limit of soil pollution by heavy metals can be

considered to be the natural concentrations of the metals occurring in the soil. The upper limit of the metals content will depend on the effects of increasing the concentrations on:

a. Biological life in the soil.

b. Plant growth.

c. Resulting concentrations in plants for human and animal consumption.

d. The concentrations in groundwater and open water courses.

At the moment there are no legal standards in force in any European country for soil pollution by heavy metals because scientific investigations designed to identify the upper limits are still in full progress. The present state of affairs with regard to the possibility of setting limits will be discussed in the following paragraphs.

Lower limit

252. The natural content of the clay soils of southern Holland can be taken as the lower limit. In the absence of any data on this, the figures of comparable soils can be given. Table 23 shows the metal content of river clays in the Maas and Waal area.

Table 23

Heavy Metal Content of River Clays in the Maas and Waal River Area

| Metal | Content, ppm |
|---|---|
| Cadmium | 3 |
| Mercury | 0.2 |
| Lead | 40 |
| Copper | 40 |
| Zinc | 140 |
| Nickel | 30 |
| Chromium | 90 |

Upper limit

253. In regard to the use of waste substances in agriculture such

as compost and sewage sludge that have high heavy metal contents, agricultural bodies need scientifically based standards for the metal concentrations that can be tolerated in soil. Although preliminary investigations on this have not yet been completed, provisional standards have been set up. Table 24 gives the limits in the soil as laid down by the West German Ministry of Public Health. It must be assumed that these levels are geared to the most sensitive type of soil, low humus sandy

Table 24

Limits of Metals in Soil for Agricultural Use

| Element | Limit, mg/kg |
|---|---|
| Beryllium | 10 |
| Chromium | 100 |
| Nickel | 100 |
| Cobalt | 50 |
| Copper | 100 |
| Zinc | 200 |
| Cadmium | 5 |
| Mercury | 5 |
| Lead | 100 |

soil. These standards also pay no attention to the difference in types of soil, i.e., the amount of $CaCO_3$ and clay minerals that are the chief factors in determining the amount of metals reaching the plant. The toxic limit for zinc on arable land would then be 250 to 300 mg/kg. A further point is that the limits for acid soils will be different. As regards copper, Henkens[18] gives a Cu-$HNO_3$ figure of 50 for arable land and 80 for pasture land. The total copper content may thus be a little higher. Since the limits apply to the most sensitive crops on low humus sandy soils and not for confined disposal areas, the whole matter is under discussion at the moment.

254. In order to find out what possibilities there are of foresting soils that have been created with dredged material, experimental

plantations have been cultivated in a number of places. Although high concentrations of certain metals were found in the leaves of some species of trees, they did not give rise to any cases of poisoning. So far, no studies have been made of the metal content in soil where toxic phenomena will become apparent in certain kinds of trees. Thus, no limits for metals in soil can be given at this time with regard to tree planting either. It must be concluded from the above-mentioned experimentation with plantations on disposal sites that the level of heavy metals contained does not inhibit the growth of the types of trees tested. In this case, therefore, the maximum level must be determined in connection with possible contamination of groundwater and open water courses.

255. The upper limit in soil used for recreation grounds, housing developments, and industry is determined by the quantities of metals that may be allowed to affect the groundwater and open water courses. The investigation being conducted at the moment indicates that the mobility of the metals in the soil can vary considerably from metal to metal. This is also influenced by soil factors such as $CaCO_3$ content, organic matter content, cation exchange, and phosphate content. Findings so far show that the quantities of metal that reappear in the ground and surface water every year for a given degree of soil pollution can only be established by taking soil measurements. Limits can thus only be laid down after closer examination has been made of the soil actually polluted by metals.

## Treatment Methods for Desalinization of Sand

256. During dredging and disposal operations, a number of measures can or even should be taken to prevent unacceptable environmental effects. Some of these measures have been indicated in other parts of the report. Only desalinization of sand will be discussed in the following paragraphs.

257. If sand from a saline environment is brought ashore, a sizable amount of salt comes with it, as every cubic metre of sand contains

about 400 $\ell$ of water, and every litre of water contains 19,000 mg of Cl , under conditions prevailing in Holland. The sand has to be desalted, especially if a great quantity of sand is to be placed where salt intrusion is unacceptable and if no effective measures can be taken to prevent it from happening.

258. Two desalting methods are commonly used; in both cases fresh water is used to replace the saltwater. The first method consists of the continuous vertical mixing of a saltwater-sand mixture with a countercurrent of fresh water (Figure 48). The sand continues its downward path, while the now brackish water flows from the overflow. The principal drawback of the system is the danger of a nonmixing condition, where there is a downward motion of the saltwater-sand mixture in one part of the cylinder and an upward motion of fresh water in a different part. Therefore, a large quantity of fresh water is needed; the system does not seem to be very attractive unless an extensive supply of fresh water is available.

259. The second method depends on the permeability of the sand. A column of sand is desalted by flushing with fresh water (Figure 49). The amount of fresh water needed is less than in the vertical mixing method, and the sand can be dewatered (retained moisture content 15 percent by volume). The flushing takes some hours, depending upon the permeability of the sand and the height of the column. The permeability and hence the necessary time is very sensitive to clay particles, and the filter is susceptible to chokage. The container has to be emptied by a grab, which can take quite some time. In the Rotterdam area, this system is to be applied shortly on a contract where a maximum amount of salt (300 mg $Cl^-/\ell$) has been set.

260. As a last possibility, under certain favorable conditions, one can let nature do the work by dumping the sand somewhere else and letting the rain leach the salt water. After some time the sand can be transported to its final destination.

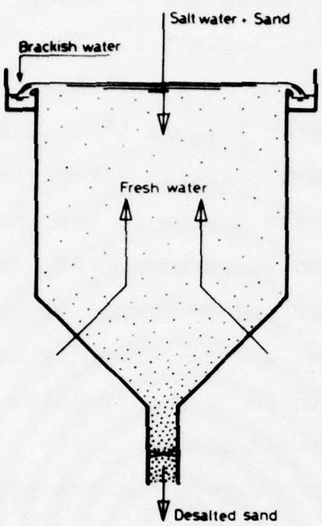



Figure 48. Mixing method for desalinization

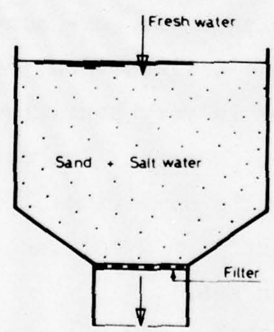



Figure 49. Flushing method for desalinization

## PART X: REVIEW AND EVALUATION

261. When reviewing the results of the assessment of European dredging practices and dredged material containment and reclamation methods, two approaches are possible. In the first approach, one can compare practices and methods of the different countries of Europe; in the second approach, one can try to compare generalized European methods with those in the United States.

262. Starting along the lines of the first approach, it is remarkable that the differences within Europe are not of great importance. Technically speaking there is a general tendency to balance quantities to be excavated and to be filled for each project. Acquiring land for disposal purposes on the basis of long-term planning (zoning) is attempted in all countries visited. Concerning dredged material dewatering problems, the method developed in Rotterdam providing a proper drainage of precipitation is widely accepted. Dewatering is further accelerated by the horizontal drainage of groundwater through sand layers (Hamburg) or through drain pipes (experimental system in Rotterdam). The dewatering techniques applied in Europe have proved to be so efficient that fine sediments can economically be used to reclaim low-lying lands for purposes varying from recreation to industrial zones.

263. Comparing the technical developments in Europe with those in the United States, some differences can be noted. One of the most surprising facts is the complete absence of bucket dredges in the United States, while this type of equipment is considered a very suitable one for maintenance dredging in Europe. This is mainly because a relatively high solids concentration can be achieved in soft fine sediments with the bucket dredge. There is of course a direct relation between the density of a mixture dredged and the subsequent dewatering problems of such a mixture. Common in the United States and in Europe is the concern about the contamination of dredged material with heavy metals, pesticides, and other pollutants. It is regretted that the dredging industry is often blamed for creating pollution when, in fact,

such is not the case. It is clear, however, that due to dredging operations polluted material is stirred up, mobilized, and transported. So far, however, there is not sufficient insight in the ecological system to decide which is the least objectionable approach to contaminated sediments: disposal on land or dumping at sea. Leaving the sediments where they are and accepting the social and economic consequences of shoaling harbors has not been considered in Europe until recently; the tendency is to continue dredging carefully until more information is obtained. Insofar as disposal on land is concerned, the only concrete information available at this moment is the fact that care is recommended with respect to human consumption of products grown on contaminated material in disposal areas. Although it cannot be stated in general that these products are unsuitable for consumption, it is strongly advised not to consume such products daily in large quantities and that an intensive control on the quality of these products be maintained. In The Netherlands it is particularly recommended not to grow leafy vegetables on disposal areas; some other food crops are also suspect.

264. It can be concluded that reclamation and dewatering techniques for dredged material as encountered in western Europe are readily available. In other circumstances, however, these techniques may possibly have to be adapted or replaced by others. It is further strongly recommended that research efforts into the behavior of contaminated dredged material be intensified and that the research efforts both in the United States and in Europe be coordinated wherever possible.

## REFERENCES


1. Thorn, M. F. C., "Loading and Consolidation of Dredged Silt in a Trailer Suction Hopper Dredge," Paper B1, Proc. 1st Int. Sym. on Dredging Technology, BHRA Fluid Engineering, Cranfield, Bedford, U.K. (September 1975).

2. Tiederman, W. G. and Reischman, M. M., "Tien Jaar Technische Adviescommissie voor de waterkeringen," The Hague, 1974 (In Dutch).

3. Tiederman, W. G. and Reischman, M. M., "Ontwerpaspecten van wegdrainage," Mededeling No. 36, Stichting Studiecentrum Wegenbouw, Arnhem, 1974 (In Dutch).

4. Nieuwenhuis, J. D., "Development of Bearing Capacity of Hydraulically Transported Sand."

5. Dixhoorn, J. van et al., "Recent Experience of Coastal Engineering Works in the Netherlands, with Special Emphasis on the Use of Sand and Gravel," Proc. 23rd International Navigation Congress, Ottawa, 1973.

6. Agema, J. F. et al., "Development of Coastal Protection in the Netherlands," Proc. 2nd Ocean Development Conference, Tokyo, 1975.

7. Agema, J. F. et al., Kostennormen voor aannemersmaterieel, NIVAG, 5th Edition, SAMSON, Alphen aan de Rijn, 1974.

8. Peeters, J. P. and Stuurman, F. J., "Beplantingsproef Broekpolder," Report No. 4, Stichting Bosbouwproefstation "De Dorschkamp," Wageningen, Intern rapport No. 62, 1974.

9. Stuurman, F. J. and Peeters, J. P., "Bos op bagger uit de Rotterdamse havens," (1) Groen, January/February 1975.

10. Willet, J. R., "Soil Physical Behavior of Spouted Mud Dredged from the Rotterdam Ports (furrowing of Rotterdam mud deposits)," Adviesbureau Arnhem, 1974.

11. Glopper, R. J., "Subsidence After Drainage of the Deposits in the Former Zuyderzee and in the Brackish and Marine Forelands in the Netherlands," Van Zee tot Land No. 50, Staatsdrukkerij en Uitgeversbedrijf, The Hague.

12. Smits, H. et al., "De Fysische, chemische en microbiologische rijping der groden in de IJsselmeerpolders," Van Zee tot Land No. 32, Staatsdrukkerij en Uitgeversbedrijf, The Hague.

13. Groot, A. J. de, "Origin and Transport of Mud in Coastal Waters from the Western Schelde to the Danish Frontier," Developments in Sedimentology, 1964, pp. 91-103, Amsterdam.

14. Groot, A. J. de, Heersma, E., and Driel, W. van, "Zware metalen in fluviatiele en marine ecosystemen," Prox. Symposium: Waterloopkunde in dienst van industrie en milieu, Delft, 1973.

15. Cooperative Research Report No. 46, Report of the Working Group on Effects of Fisheries of Marine Sand and Gravel Extraction. Int. Council for the Exploration of the Sea Charlotterlund Slot, Charlotterlund, Denmark.

16. Edwards, C. A., "Persistent Pesticides in the Environment," The Chemical Rubber Cy, 1970.

17. Edwards, C. A., "Standards for Water Used for Irrigation and Drinking," United States Public Health Service, 1968.

18. Henkens, C. H., "Sewage Clarification Mud in Agriculture, Bedrifjs-ontwikkeling" Vol No. 6, 1975, pp. 98-103.

19. Rees, A. J. van et al., "Experiences with Tidal Salinity Model Europoort," Proc. 13th Coastal Engineering Conference, Vancouver, July 1972.

20. Riessen, G. van, "The Approach to the Europoort Harbors in Rotterdam," Land and Water International, Vol No. 5, 1968-1969.

21. Palmer, M. D., "Water Quality Study Proposal for Tejo Estuary, Portugal," from pg A30.

## APPENDIX A: PORTS CONSIDERED

1. Dredging activities were thoroughly investigated at major ports in the following countries: Belgium, France, West Germany, The Netherlands, Portugal, and the United Kingdom. Results of these investigations are described in detail in this appendix. A brief summary of statistics relevant to dredging and disposal practices at each port is contained in Table 2 of the main text of this report.

### Antwerp, Belgium

2. The port of Antwerp is situated on the right bank of the Scheldt River, about 33 km from the North Sea (Figures A1 and A2). The river is navigable by vessels up to 13 m draft. The port consists of two parts: quays along the river front and a large dock system connected to the river by five locks.

3. The Port Authority is responsible for the dredging in the port proper, i.e., excluding the channels in the estuary and at sea. Maintenance dredging in the port part amounts to 2.5 million $m^3$ annually and is carried out by the Port Authority with its own equipment (bucket dredges, grab dredges, barges, and reclamation dredges). The dredged material from the port area is deposited on land in disposal areas. The pipe transport system covers a distance of about 2300 m. There is no special method of reclamation; only one lift 5 to 6 m thick is used. Dewatering is said to be no problem. The transport water is pumped back to the dock area. The major part of the disposal areas has an industrial designation. In the entrances to the locks, agitation dredging is carried out with a steel beam pulled by tugs. Downstream of Antwerp, maintenance dredging in the Scheldt River is carried out with hopper dredges by contractors under supervision of the National Authorities. The dredged material is dumped in deeper parts of the estuary.

4. Until now there have been no environmental restrictions. A few analyses of heavy metal content of the dredged material are


Figure A1. Map of Europa

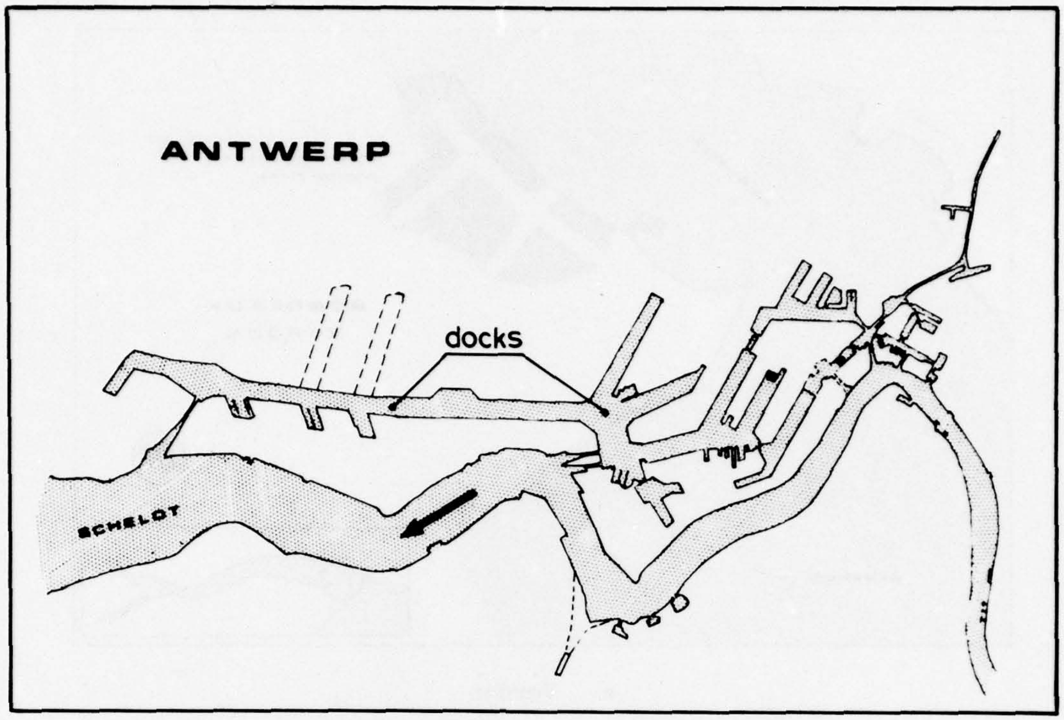


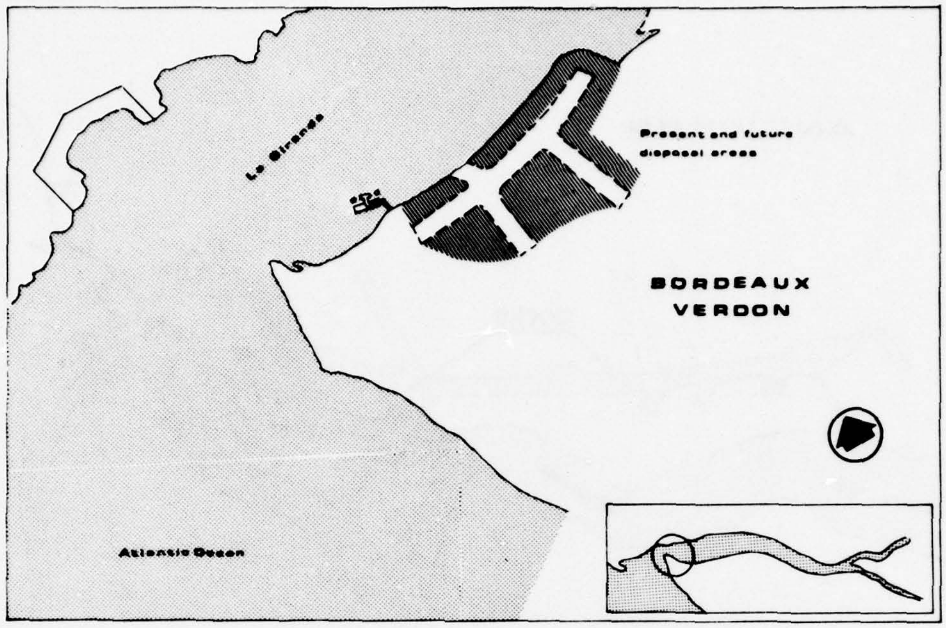

Figure A2. Harbor of Antwerp

available; these show the heavy metal content not to be dangerous and to be only a fraction of that encountered in the port of Rotterdam. There are insufficient data, however, to conclude whether or not the dredged material is polluted (see Part VIII of this report).

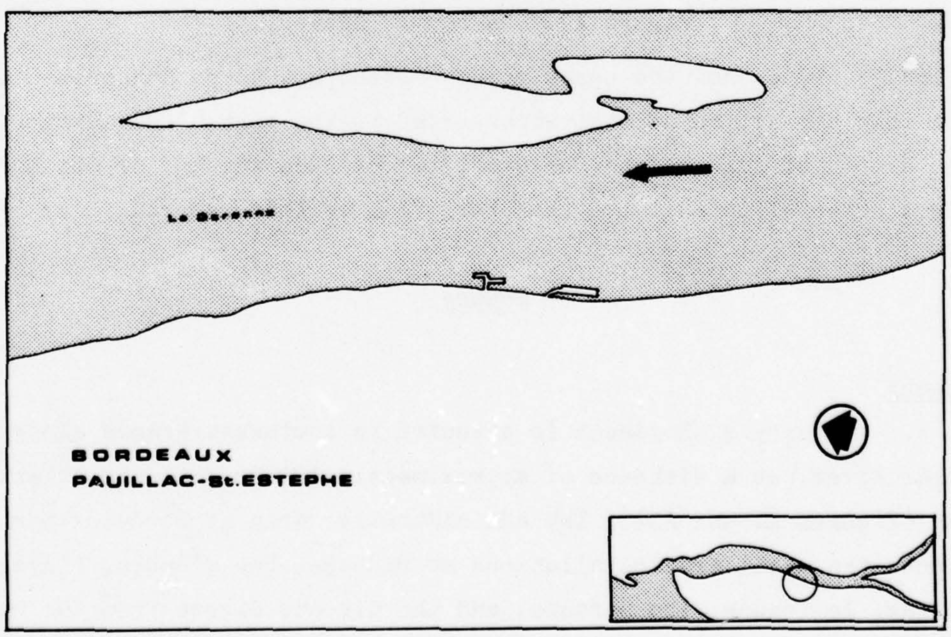
## France

### Bordeaux

5. The city of Bordeaux is situated in southwest France along the Gironde River, at a distance of approximately 100 km from the Atlantic Ocean (Figures A1 and A3). The administrative area of Bordeaux port includes the auxiliary installations at Bassens, Bec d'Ambes, Blaye, Pauillac, le Verdon, the Garonne, and the Gironde Rivers from the upstream boundary to the sea (excluding the small ports and the bank of the Gharente-Maritime), Dordogne, Bec d'Ambes to the 40-km sign, and the outer harbor of Verdon. Entrance to the port in the Gironde is

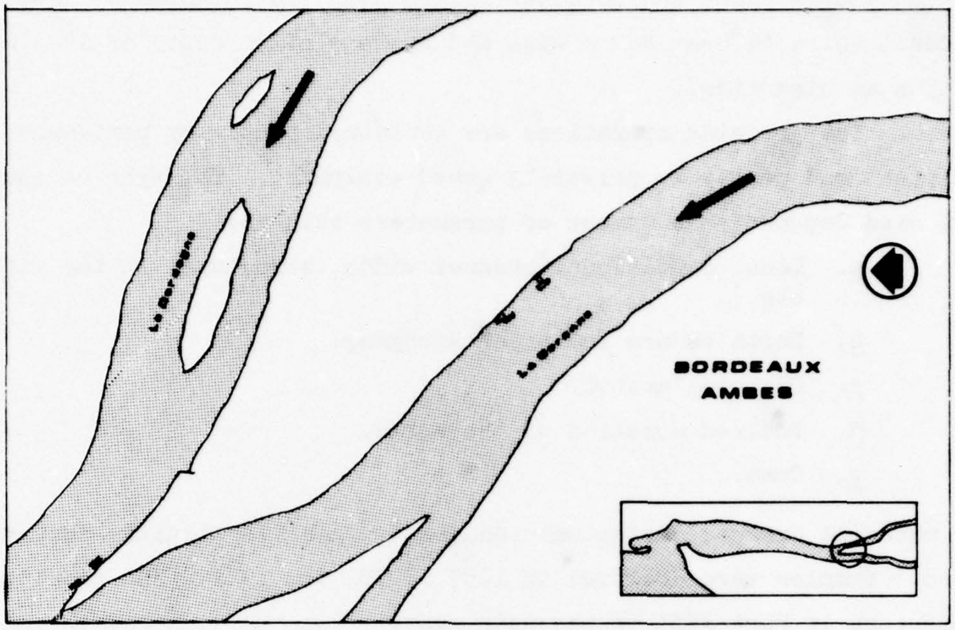



a. Verdon

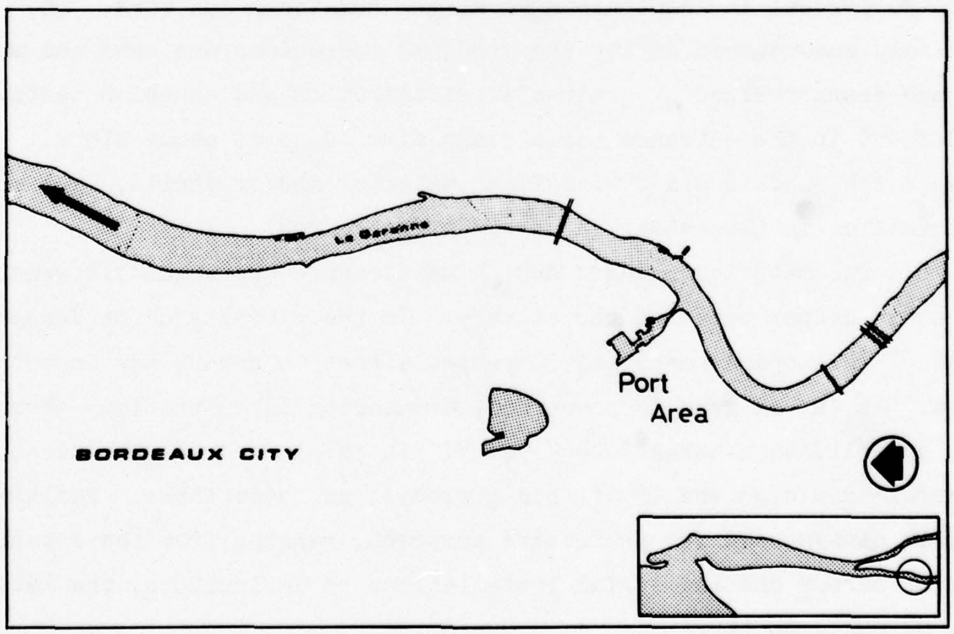



b. Pauillac

Figure A3. Harbor of Bordeaux (Continued)




c. Ambes




d. City

Figure A3. (Concluded)

between Coubre Point and Cordouan lighthouse, via the Grande Passe de l'Ouest, which is over 400 m wide and has a minimum depth of 14.5 m (17.5 m at high tide).

6. The dredging operations are performed partly by port-owned equipment and partly by privately owned equipment. The type of equipment used depends on a number of parameters such as:

a. Local conditions (channel width, structures in the vicinity, etc.).

b. Depth before and after dredging.

c. Disposal method.

d. Desired duration of the works.

e. Cost.

The material dredged during maintenance dredging is slightly contaminated. Samples were analyzed in 1967, 1970, and 1974. The results are summarized in Part VIII of the main text.

7. The annual quantity dredged is between 15 and 20 million $m^3$, 80 to 90 percent in maintenance work, the remainder new work. The materials encountered during the dredging operations are sand and mud and are characterized by grain-size distribution and cohesion tests. Sand found in the entrance has a grain size ($d_{50}$) of about 250 μ. Locally the sand is mixed with finer material and/or shells. The mud predominates in the estuary upstream of Le Verdon.

8. The material dredged during maintenance operations is generally dumped in deeper parts of the estuary. In the vicinity of Le Verdon, however, maintenance material is pumped ashore to create new industrial areas. As far as sand is concerned, dewatering is no problem. For the mud, consolidation takes 3 to 4 years. It is planned to make use of the Amphirol* and disc wheel* if this period is not acceptable. Reclaimed land is always used for productive purposes, ranging from the establishment of harbor and industrial installations to agriculture, the latter only on mud deposits.

---

* See paragraphs 111 and 112 of the main text.

Dunkirk

9. The port of Dunkirk is situated in the extreme northwest of France along the coast of the English Channel (Figures A1 and A4) at the southernmost part of the North Sea. The port is presently divided in two separate systems. The old port, situated in the east, consists of the east outer harbor and an inner harbor basin accessible through three locks. The latest extension of the port, consisting of the west outer harbor and a tidal basin, is still under development and not yet connected with the old harbor. In the east outer harbor, the Exutoire Canal discharges polluted water from the hinterland.

10. Average annual capital dredging amounts to 18 million $m^3$, maintenance dredging to approximately 2 million $m^3$. The types of soil encountered are sand with $d_{50}$ equal to 200 μ and mud. The materials are characterized by granulometry and density tests, respectively, to judge their dredgeability. A part of the material resulting from maintenance dredging is polluted. The material has been recently analyzed; data are presented in Part VIII of the main text. The pollution is attributed to the influence of the above-mentioned Exutoire Canal.

11. Most of the dredging work is carried out by contractors under supervision of the Port Autonome de Dunkerque (Port Authority). The dredging equipment used depends on the eventual use of the dredged material. Mud from maintenance dredging and material from capital works that are unsuitable as fill material are dumped at sea by trailing suction hopper dredges. Sandy material with a silt content of less than 4 to 5 percent is used for reclamation and handled in general by cutter suction or plain suction dredges. Disposal areas are reclaimed for the purpose of industrialization. Since sands with a high silt content are rejected as fill material, dewatering causes no special problems. The disposal site at sea (2 miles (3.2 km) offshore) is selected on the basis of technical reasons (recirculation). Environmental impacts have not been studied. Turbidity due to dredging or to dumping is not considered to be a problem in comparison to the natural turbidity. The disposal site was so popular among fishermen that fishing had to be restricted in the interest of safety of navigation.

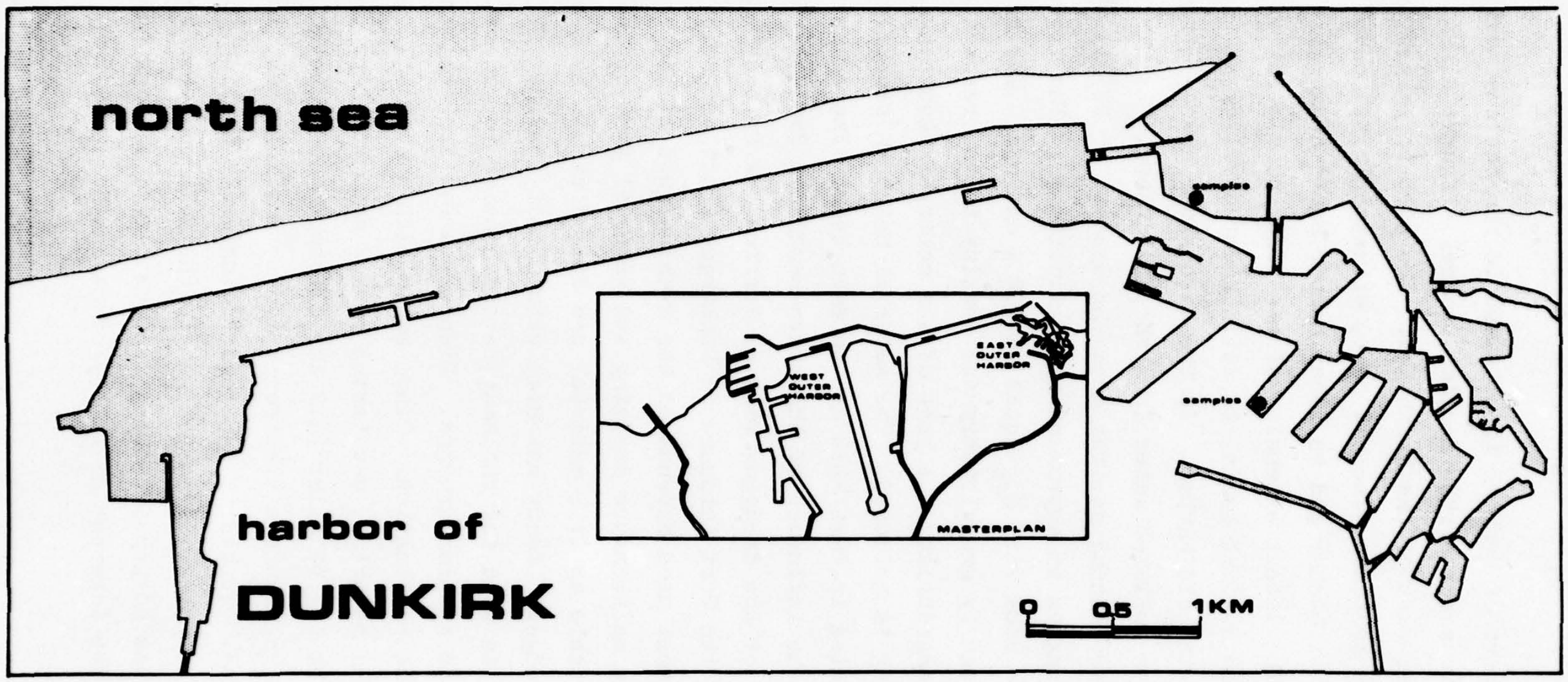



Figure A4. Harbor of Dunkirk

Le Havre

12. Le Havre is situated at the mouth of the estuary of the Seine River (Figure A1). The port consists of an outer harbor, a tidal basin, and a number of dock basins. Along the bank of the Seine, an industrial area is being reclaimed by making use of material dredged from channels and harbor basins (Figure A5). Twenty kilometres north of Le Havre proper, at Cap d'Antifer, a separate deepwater port has been constructed.

13. Maintenance dredging is mainly carried out by the port itself, often supported by the ports of Rouen and Bordeaux; capital dredging is often carried out by contractors. Maintenance dredging amounts to approximately 1.5 million $m^3$ annually, whereas the quantity of capital dredging varies considerably from year to year. The material resulting from maintenance dredging is mud; material from capital dredging is mainly fine sand sometimes mixed with gravel or pebbles. The mud is not used for reclamation and is dumped in the sea at a distance of about 12 km. Sand dredged from channels and inner harbor basins is used to raise land by about 2 m to make it suitable for the construction of harbor installations or industrial buildings. Dewatering of the sand ($d_{50}$ of about 120 μ) in layers of 2 m does not cause any problems. The disposal area is accessible after about 2 weeks and is released to future users about 3 months after the disposal operations. There is little or no information regarding the environmental effects of the dredging process as such. Local fishermen seem to fear a negative influence from the morphological changes in the estuary.

Marseille

14. The Port Autonome de Marseille includes a number of harbors of various importance such as Carente, Etang de Berre, Fos, Lavera, Port de Bouc, etc. The tidal range of the Mediterranean Sea at Marseille is virtually nil and great natural depths extend close to the shore. The old harbor at Marseille proper has a depth of approximately 12.5 m. A new deepwater port developed west of Marseille near Fos is in the delta of the Rhone River (Figures A1 and A6).

15. Dredging activities concentrated in the area around Fos are restricted to capital dredging and the average annual dredging, amounts

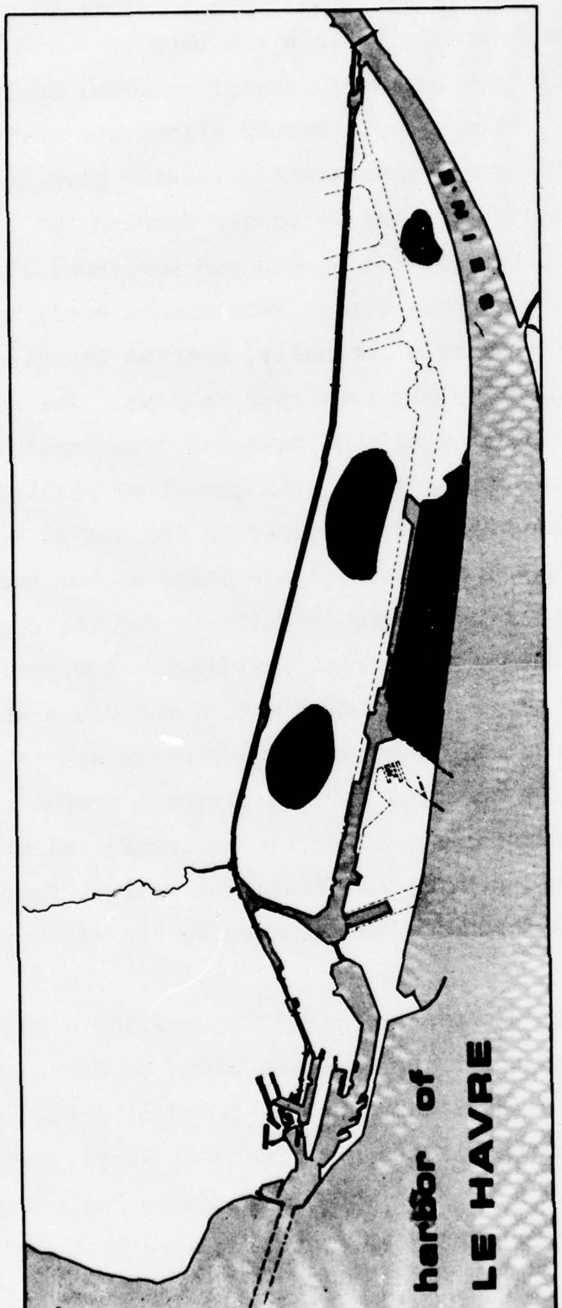



Figure A5. Harbor of Le Havre

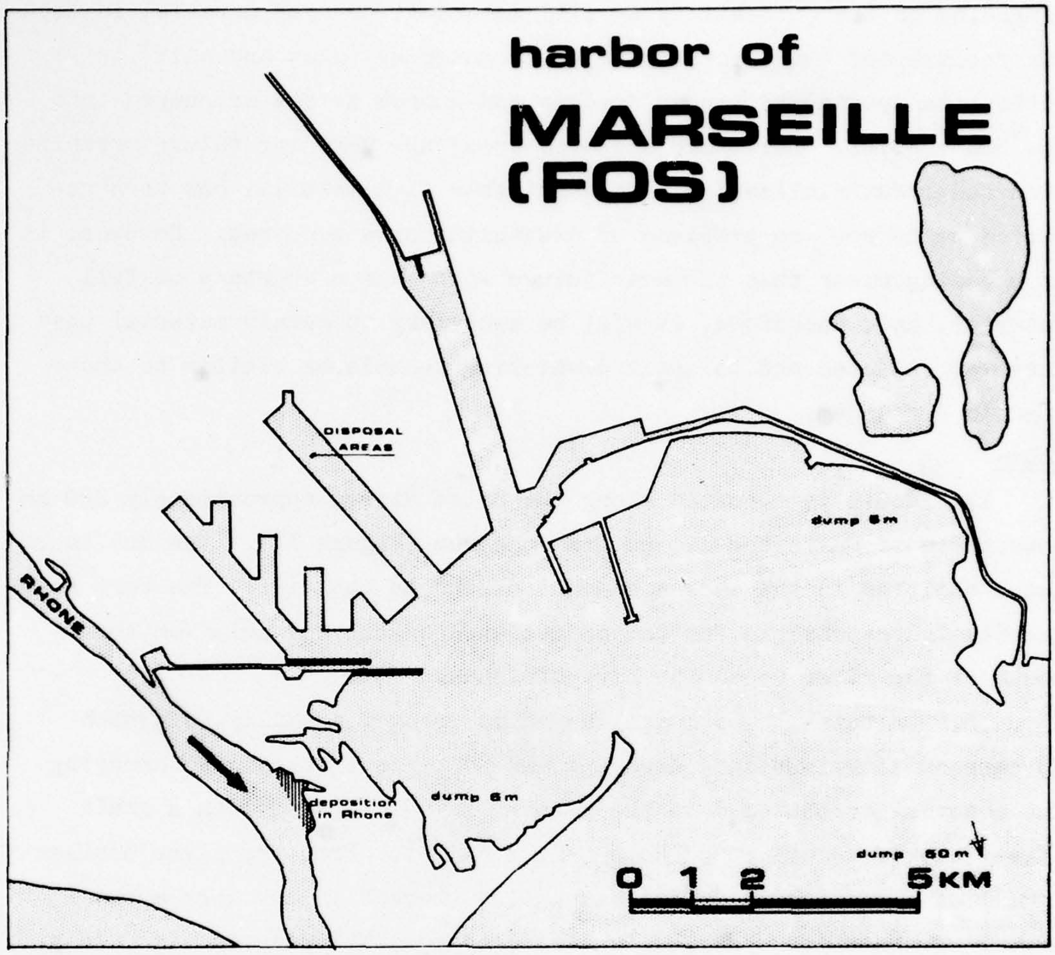



Figure A6. Harbor of Marseille (Fos)

to 14 million $m^3$. The types of soil encountered differ from place to place, but, on the average, 30 percent is silt, 50 percent is sand, and 20 percent is gravel (the latter sometimes cemented). Probably as a result of the complexity of the soil properties, a wide variety of tests are performed to characterize the material. For sand it is the grain-size distribution; for silt (mud), sedimentology, plasticity index, cohesion, and interstitial pressure are measured. Drilling characteristics of the shell auger method in gravel are also analyzed. The results of these analyses are made available to the contractors along with the specifications.

16. Since all the dredged material is virginal, it is not polluted.

Depending on the suitability as fill material, dredged material is used for reclamation or rejected. Rejected material (clay and silt) is either transported by hopper dredges and dumped at sea or pumped into the Rhone River. Reclaimed disposal areas are used for future urbanization and industrialization. As unsuitable fill material has been rejected up to now, no problems of dewatering have occurred. However, it is becoming clear that the near future will show a shortage of fill material, and, therefore, it will be necessary to retain material that once was rejected and to apply dewatering techniques similar to those used in Rotterdam.

Rouen

17. Rouen is situated along the Seine River, approximately 220 km downstream of Paris and 120 km from the sea (Figure A7). The drafts of ships admitted in the access channel depend on the tide. The Port Authority is responsible for the maintenance of the channel from the mouth of the river up to the city of Rouen.

18. In total, 5 to 6 million $m^3$ is dredged annually, of which 75 percent is maintenance dredging and 25 percent is capital dredging. The material encountered in the estuary is mainly sand with a grain size ($d_{50}$) of about 120 μ (4 to 5 million $m^3$). From the river another 1 million $m^3$ of mud is dredged annually, whereas in new work a small amount of gravel and pebbles is also dredged. The material is mainly characterized by its grain size. Material from maintenance dredging is believed to be polluted, but no concrete data are available for confirmation. Dredging is carried out by the Port Authority, which operates a number of bucket dredges, trailing hopper dredges, and cutter suction dredges.

19. The locations of disposal areas for the dredged material depend on the dredging locations. Maintenance dredging in the estuary is mainly performed with trailing suction hopper dredges. The discharge material is dumped near the river mouth, not too far from Le Havre. In the upstream reaches of the river dredging is performed with bucket dredges. In view of the distance to sea, the dredged material is disposed on land or in channels of the river that are to be closed off to

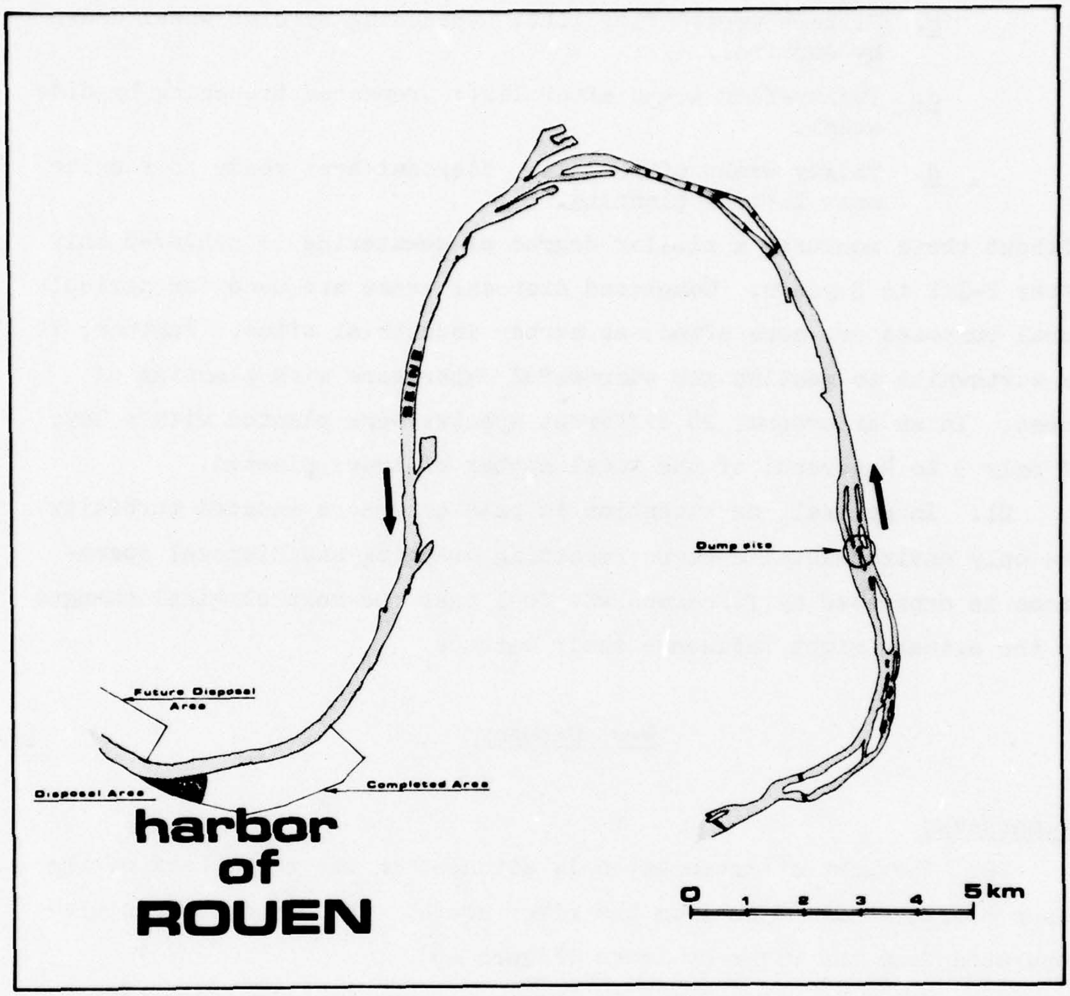



Figure A7. Harbor of Rouen

improve the flow regime. In the near future, a trailing hopper dredge discharging ashore will also be applied in the upstream sections.

20. The disposal areas are, in general, diked areas along the river. The dikes are designed, on the basis of experience, with slopes of 1:1-1/2 and a crest width of 3 to 4 m, irrespective of the material. The disposal areas are divided into sections of about 5 ha each. In total, disposal areas are raised 6 m in lifts of 1.5 to 2 m. Dewatering is improved by the following procedures:

a. Eight weeks after lift: trenching by Amphirol with trenches in the direction of the natural slope.

b. Sixteen weeks after lift: trenching by disc wheel drawn by Amphirol.

c. Twenty-four weeks after lift: repeated trenching by disc wheel.

d. Thirty weeks after lift: disposal area ready to receive next lift or planting.

Without these measures a similar degree of dewatering is achieved only after 2-1/2 to 3 years. Completed disposal areas are used for agricultural purposes or, more often, as harbor industrial sites. Further, it is worthwhile to mention the successful experience with planting of trees. In an arboretum, 28 different species were planted with a loss of only 3 to 4 percent of the total number of trees planted.

21. In general, no attention is paid to dredge-induced turbidity. The only environmental concern regarding dredging and disposal operations is expressed by fishermen who feel that the morphological changes in the estuary might influence their catches.

## West Germany

### Bremerhaven

22. The port of Bremerhaven is situated on the right bank of the Weser River, about 60 km from the river mouth. The harbor basins are separated from the river by locks (Figure A8).

23. Maintenance dredging in the harbor and the river stretches amounts to 1.6 million $m^3$ annually, of which 0.3 million $m^3$ is sand and 1.3 million $m^3$ is mud. The characteristic grain size ($d_{50}$) of the sand is 200 μ; the mud contains 60 to 70 percent material of a grain size less than 50 μ. There is no information on the contamination status of the dredged material. The maintenance dredging is carried out by port-owned bucket and reclamation dredges. The dredged material is reclaimed on land. Disposal areas were used for agriculture and industrialization. The finest and most fertile material is used for areas zoned for agricultural purposes; sand and mixtures of sand and mud are used for future industrial areas. No measures are taken to accelerate the dewatering process. To allow for improved evaporation, mud is reclaimed in layers

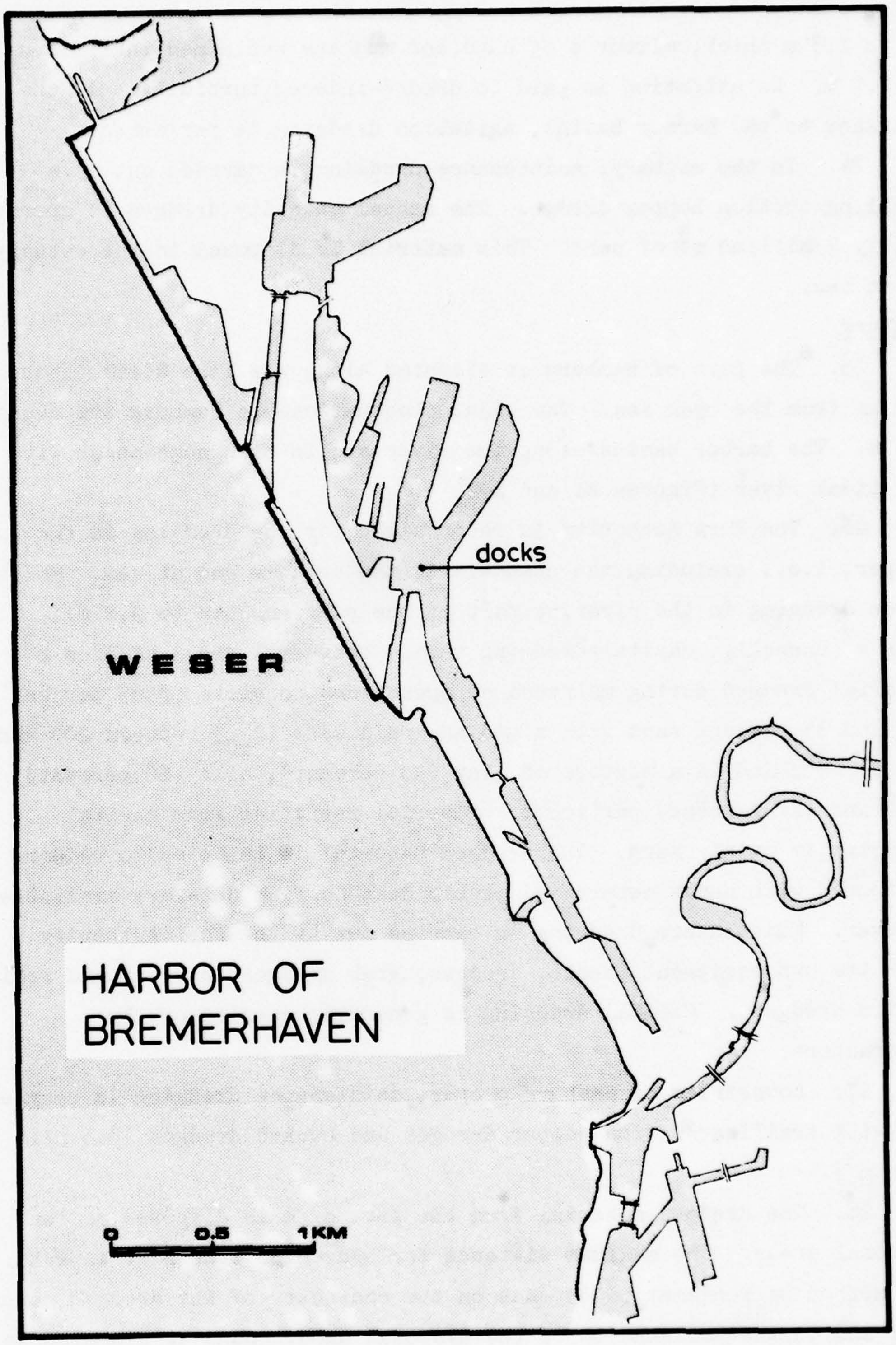



Figure A8. Harbor of Bremerhaven

up to 1.5 m thick; mixtures of sand and mud are reclaimed in lifts up to 7.5 m. No attention is paid to dredge-induced turbidity. In the entrance to the harbor basins, agitation dredging is performed.

24. In the estuary, maintenance dredging is carried out by a trailing suction hopper dredge. The annual quantity dredged is approximately 7 million $m^3$ of sand. This material is disposed in the estuary or at sea.

Hamburg

25. The port of Hamburg is situated along the Elbe River, about 110 km from the open sea. The tidal fluctuations at Hamburg are about 2.5 m. The harbor basins along the river are in open connection with the tidal river (Figures A1 and A9).

26. The Port Authority is responsible for the dredging in the port proper, i.e., excluding the channels in the estuary and at se.. Maintenance dredging in the riverine part of the port amounts to 2.2 million $m^3$ annually, capital dredging varies between 1 and 3 million $m^3$. Material dredged during maintenance operations consists of 65 percent mud and 35 percent sand with a median grain size ($d_{50}$) between 200 and 600 μ. The mud is a mixture of clay (30 percent), silt (60 percent), and sand (10 percent) particles. Material resulting from capital dredging is mainly sand. The dredged material is believed to be contaminated with heavy metals and pesticides; no firm data are available, however. Maintenance dredging is carried out by the Port Authority with its own equipment (bucket dredges, grab dredges, barges, and reclamation dredges). Capital dredging is generally carried out by contractors.

27. Downstream of Hamburg proper, maintenance dredging is carried out with trailing suction hopper dredges and bucket dredges (8.5 million $m^3$).

28. The dredged material from the port area is disposed on land in disposal areas. The maximum distance for hydraulic transport is 2 km. The method of reclamation depends on the character of the dredged material and on the designation of the disposal area. Sand is disposed in areas meant for industrial purposes. Areas are reclaimed in one lift,

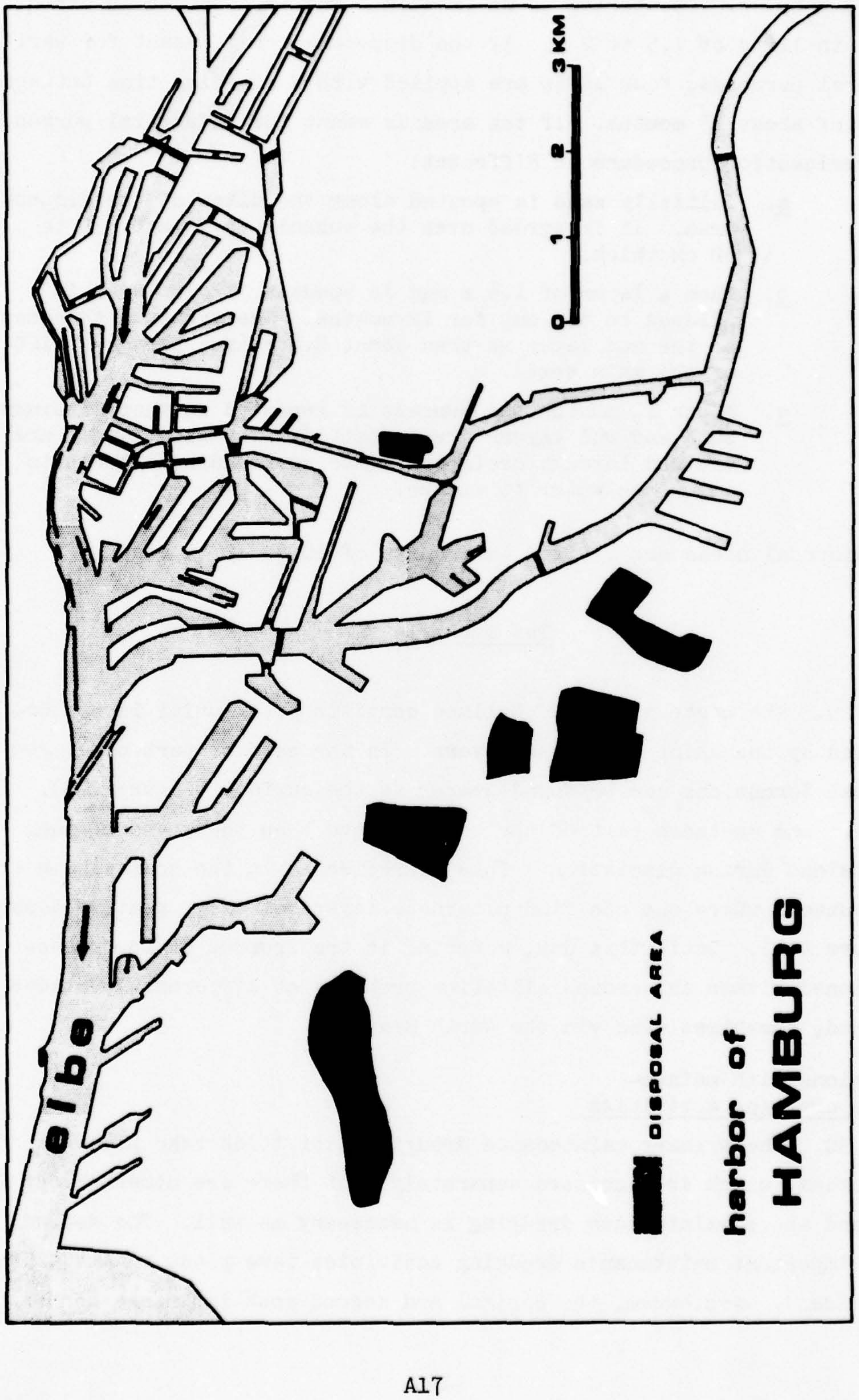



Figure A9. Harbor of Hamburg

4 to 5 m thick. Dewatering is no problem. Mud is disposed in diked areas in lifts of 1.5 to 2 m. If the disposal area is meant for agricultural purposes, four lifts are applied with a ripening time between lifts of about 15 months. If the area is meant for industrial purposes, the reclamation procedure is different:

a. Initially sand is spouted along the dikes of the disposal area. It is spread over the subsoil in a layer 30 to 50 cm thick.

b. Then a layer of 1.5 m mud is spouted. This layer is allowed to dry out for 12 months. The eventual thickness of the mud layer is then about 0.8 m (see paragraph 108 of the main text).

c. After 12 months the process is repeated so that alternate sand and mud layers are deposited. The sand layers are drained through drainpipes into surrounding ditches to allow the water to escape.

The disposal areas are divided into units of 10 to 12 ha each.

## The Netherlands

29. The western part of Holland consists of alluvial layers deposited by the Rhine and Meuse Rivers. In the eastern part older geological formations can be found nearer to the surface (Figure A10). The western and northern part of the country have been the scene of many incursions during glaciation. This is reflected in the composition of the subsoil where one can find alternate layers of clay, peat, and sand (Figure A11). Until this day, material is transported by the abovementioned rivers and causes siltation problems at different locations in Holland, sometimes even via the North Sea.

### Locations with maintenance dredging activities

30. The primary maintenance dredging activities take place in Rotterdam, which is discussed separately, but there are other places in Holland where maintenance dredging is necessary as well. The second most important maintenance dredging activities take place in Amsterdam (IJmuiden). Amsterdam, the capital and second most important harbor of

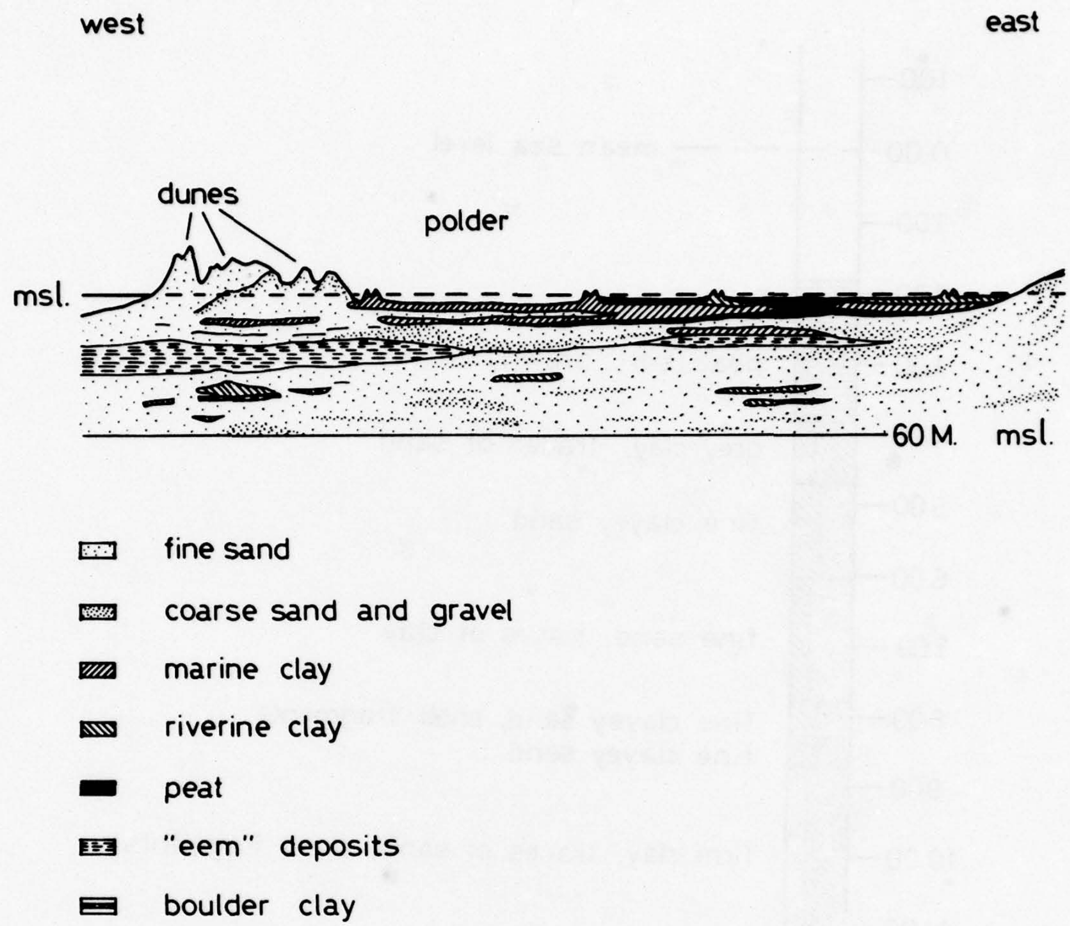



Figure A10. Geological cross section of the western part of The Netherlands

Holland, is linked to the North Sea by a 30-km canal. The entrance of the canal (IJmuiden) is protected by two breakwaters and siltation (2 million $m^3$ per year) takes place. Other harbors along the coast where maintenance dredging takes place occasionally are (Figure A12): Terneuzen, Vlissingen, Scheveningen, Den Helder, Harlingen, and Delfzijl. The quantities involved and the disposal techniques used do not justify a separate discussion. The same applies to harbors along the main rivers, where the dredged material is mainly sand.

Locations with
capital dredging activities

31. At several locations in The Netherlands, capital dredging has

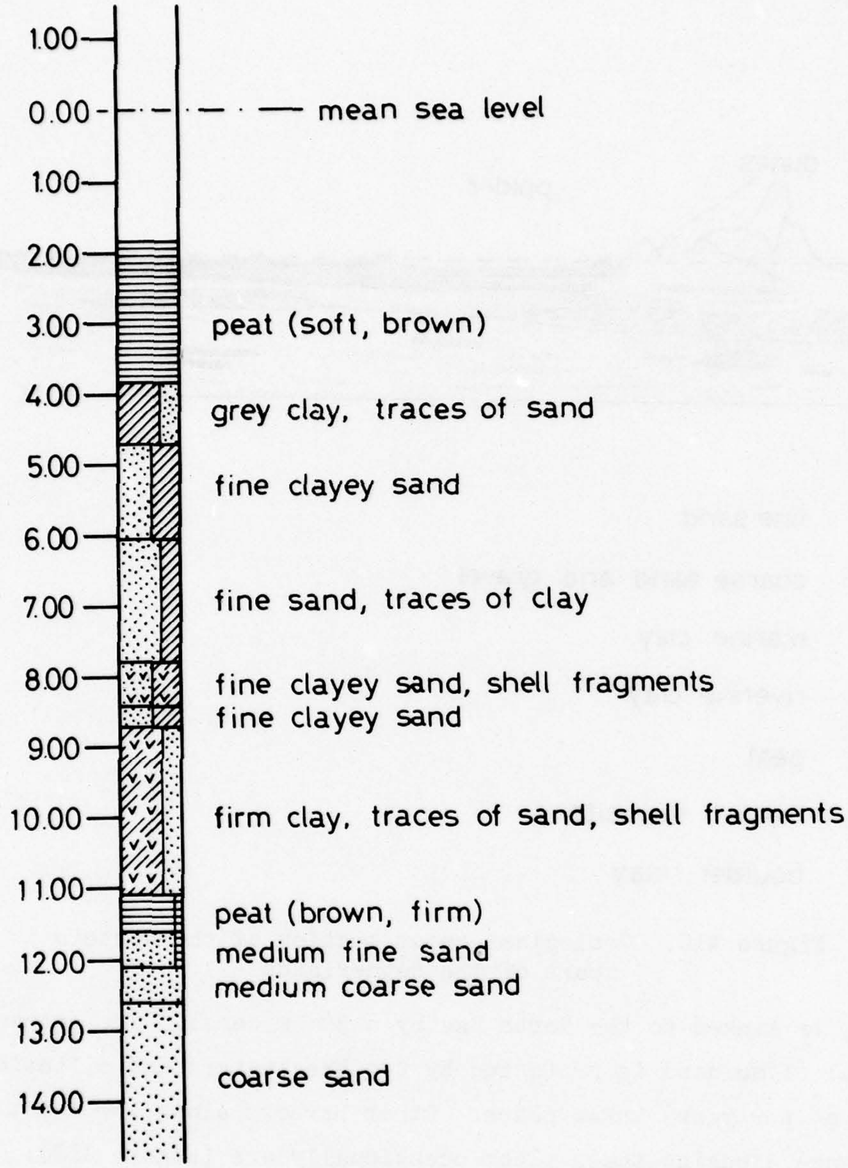



Figure A11. Typical result of boring in the western part of Holland

been and still is performed. As far as possible a productive use is made of the dredged material for reclamation, dike construction, etc., within one and the same project. In the past no sophisticated techniques have been used to improve the dewatering of clayey soils. Even in recently completed projects, the subject of dewatering has been given a very limited attention. An example of a recently completed project is


Figure A12. Map of The Netherlands

the construction of a canal, connecting the Rhine and Scheldt Rivers (Figure A13). Here, 35 million $m^3$ was dredged and disposed of, mainly in confined disposal areas. There are no concrete plans for productive use of the disposal areas. Measurements on dewatering have been performed merely to assess the capacity of disposal areas, but the results have not yet been evaluated. Part of the disposal took place in an unconfined area (former suction pit) in the Eastern Scheldt near the vicinity of mussel beds. The mussels were not affected by the increased turbidity. (Note: the material (clayey silt and find sands) was not contaminated.)

Polders

32. The geological development of Holland created a lot of shallow lakes. Because of semi-impervious subsurface clay layers, it appeared possible to pump the lakes dry and thus enlarge the area of arable land. The construction of these polders started in the early Middle Ages (around 1300 A.D.) and has been a way of life for the Dutch until today. Many problems encountered in the disposal of dredged material from maintenance dredging are similar in nature to those encountered in newly constructed polders where often the top layers consist of clayey soils with a very high water content. The experience gained in polder construction was treated in Part VII of the main text.

Rotterdam

33. The Rotterdam Harbor area consists of a complex of harbors along the Nieuwe Maas, Scheur, and Nieuwe Waterweg and a recently established complex of deepwater ports with a separate entrance (Europoort). The area is shown in Figure A14. The Oude Maas and Nieuwe Maas are a part of the extensive delta of the Rhine River and, as such, part of the discharge of the Rhine flows through the Rotterdam Harbor. The river and all harbor basins are in open connection with the North Sea so that saline seawater also has free access to the harbors. The water discharged by the Rhine carries down fine sediments contaminated with industrial wastes. The density of this water is considerably lower, however, than the density of the water from the North Sea, which is relatively uncontaminated.

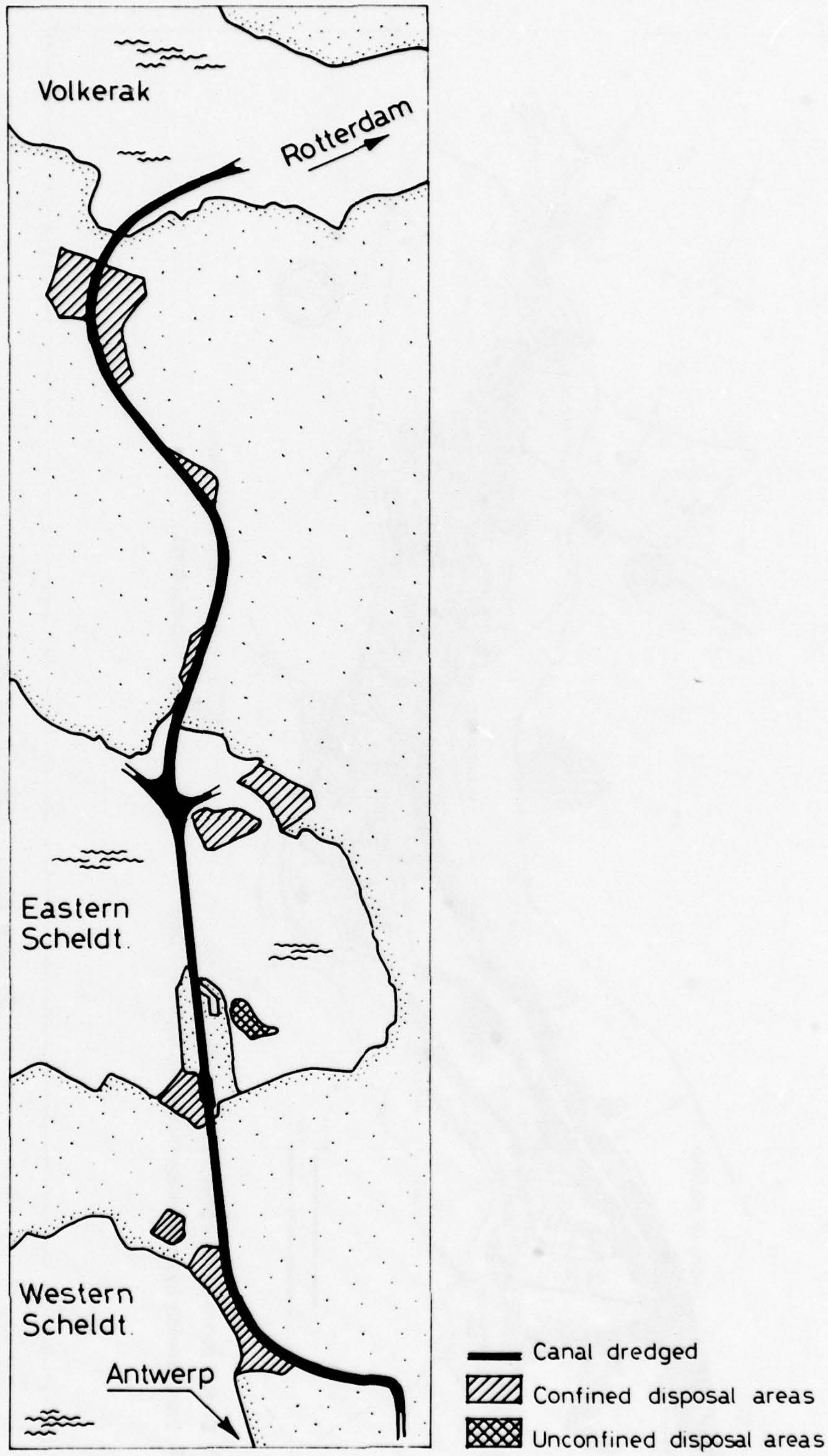



Figure A13. Scheldt-Rhine Canal

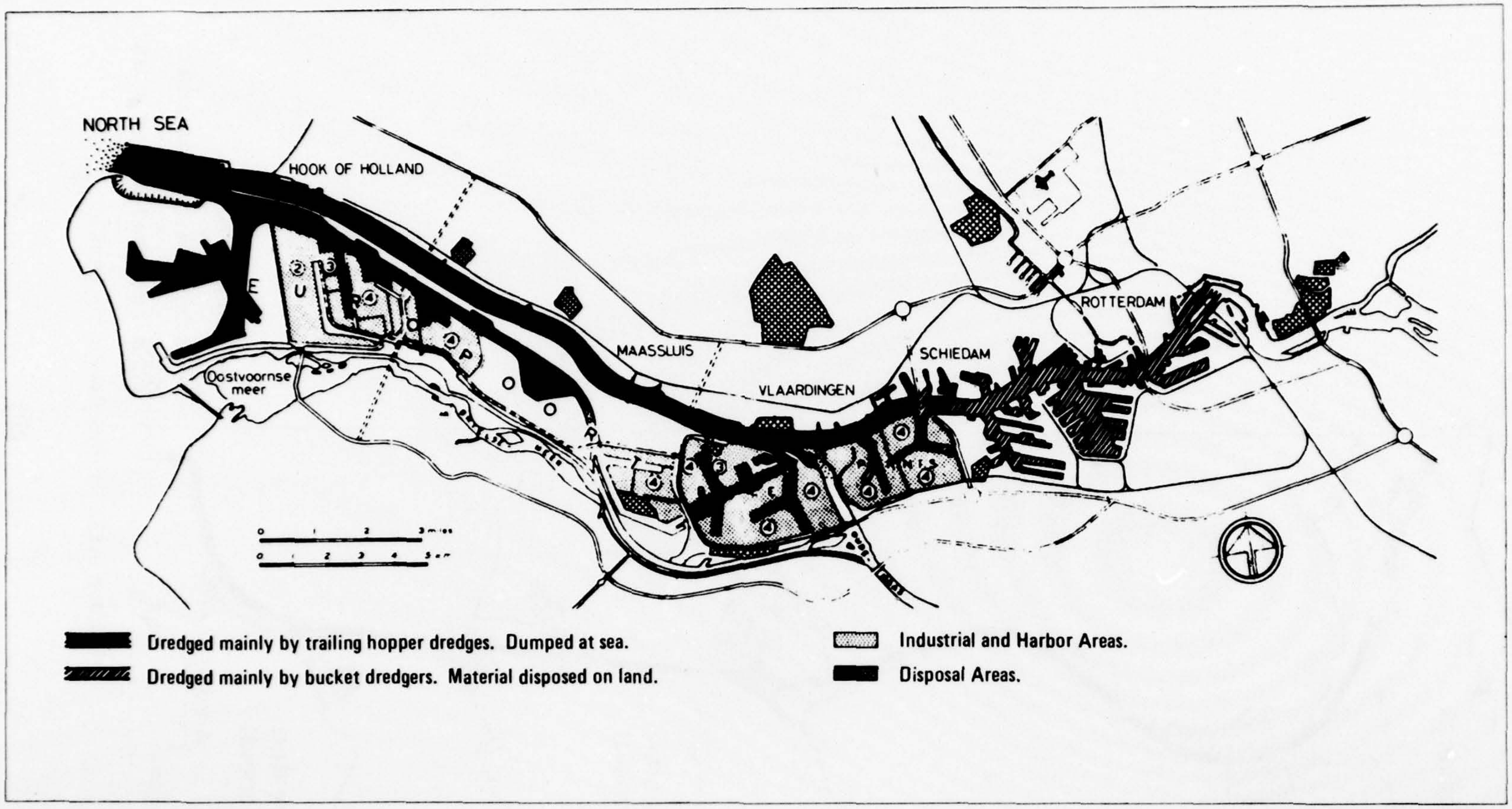



Figure A14. Harbor of Rotterdam

34. The complex hydrological and morphological processes in the estuary have been studied in detail, making use of both prototype observations and model studies.[19,20]*

35. The recently constructed harbor basins of Europoort and Botlek are maintained at depths of NAP -22 and -15 m, respectively (NAP is the survey datum that approximately coincides with mean sea level). These depths allow ships with drafts up to 21 and 14 m, respectively, to enter into the harbor basins. The other older harbors all have smaller depths, and, as a consequence of the smaller size of the entering ships, the widths of these harbor basins are also smaller.

36. The dredging operations in the harbor area since World War II fall into two types: maintenance dredging and capital dredging (new work). All dredging operations on the river and in the approach channel at sea are carried out under the responsibility of the central government (Rijkswaterstaat), whereas the municipality of Rotterdam is responsible for maintaining the required depths in the harbor basins and directly in front of the quaywalls along the river. Loading and unloading of cargo is generally performed by the private companies that rent their harbor area from the municipality. The depths in front of these private harbor areas are maintained by the municipality at a depth that is quaranteed by lease contract.

37. Insofar as <u>capital dredging</u> is concerned, the design of new extensions has always been such that the bulk of the dredged material could be used for reclamation of low-lying lands along the river, which were converted in this way into industrial or harbor areas ("making work with work").** It should be realized that this procedure was feasible as a result of three facts:

- a. The low-lying polders along the river had to be reclaimed anyhow to become suitable as harbor or industrial area.
- b. Because of their low elevation, the polders had large storage capacity.

---

* See References at the end of the main text.

** See Glossary (Appendix I).

c. The material that was to be removed was usually suitable as fill material.

38. Insofar as maintenance dredging is concerned, the disposal of the dredged material was and is more complicated, mainly because the material dredged during maintenance dredging is relatively fine. Nevertheless, techniques have been developed to use this material for reclamation and to accelerate the process of dewatering and consolidation. The quantities of maintenance dredging in Rotterdam amount to approximately 8 million $m^3$ per year for the municipality and 10 million $m^3$ per year for the Rijkswaterstaat.

39. In the harbor basins of Europoort and Botlek and in a part of the access channels, the required water depth is maintained with the aid of trailing suction hopper dredges. These dredges load the dredged material in their hoppers and transport it to a disposal area at sea (5 km offshore) or to a pit in the Europoort areas. In the remaining part of the Rotterdam Harbor area, maintenance dredging is mainly done by bucket dredges. This part of the harbor is shallower than Europoort and Botlek, the basins are narrower, and the traffic is much denser (although the size of the ships is smaller). Trailing hopper dredges would find difficulty in maneuvering due to the restricted width of the basins; moreover, the great distance to the disposal site is almost prohibitive for trailing hopper dredges. Material dredged by the bucket dredges is transported by barges to barge unloading or reclamation dredges, which pump the dredged material into disposal areas situated along the river and around Rotterdam (Figure A14).

## Portugal

40. The Port of Lisbon is situated on the Tagus River estuary, which is 25 km long and between 2 and 15 km wide (Figure A15). The tidal range is about 4 m. The port's activities are concentrated on the north bank of the estuary, where about 12 km of wharves is available.

41. Maintenance dredging activities are encountered in the same areas. The annual quantity of maintenance dredging is about 2 million $m^3$.

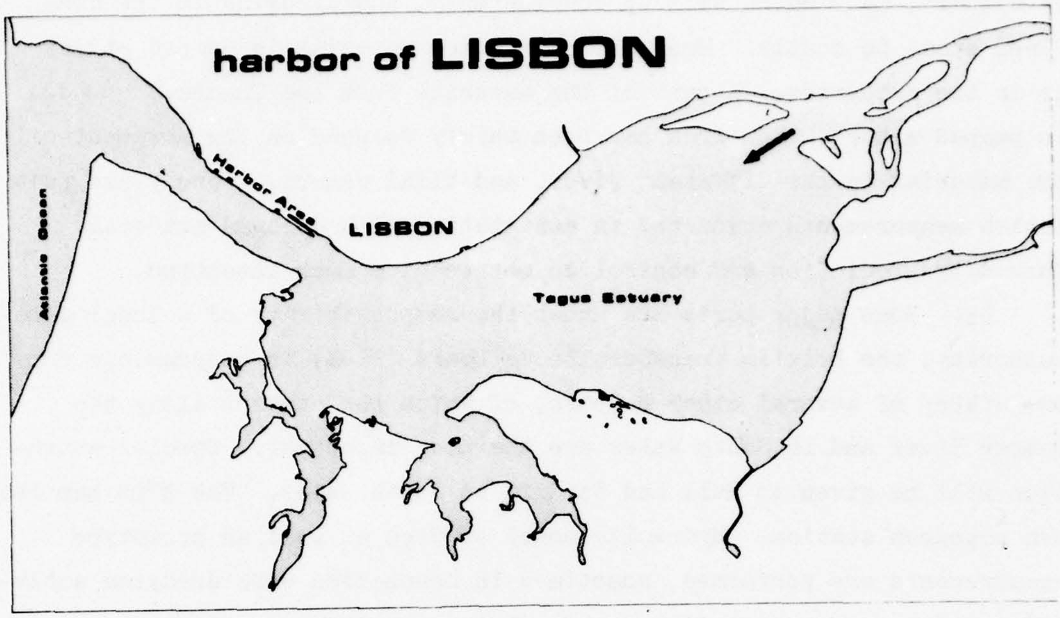



Figure A15. Harbor of Lisbon

Maintenance dredging is carried out with the port's own equipment, consisting of a bucket dredge and two grab dredges. Dredged material is mainly mud and is transported by barges and dumped in deeper parts of the estuary. About 20 percent of this material is believed to recirculate into the harbor area, a procedure that is accepted because of the higher cost of alternative solutions. In view of the increasing contamination of the estuary, land disposal of dredged material is being considered. Both the water quality and the contamination of bottom material are being studied with the aid of a mathematical model.[21]

## United Kingdom

42. The United Kingdom has many harbors situated along the lower regions of rivers. Because of the great tidal range (about 10 m) in many harbors, docks that could be impounded with the aid of lock gates were constructed along the rivers. As many of these docks can only be entered during high tide, the usage is not very flexible. In spite of the higher elevation as compared to the average water level in the river

or estuary, many docks silt up considerably, and dredging in the confined space is costly. Most of the dredged material is dumped at sea or in the estuaries. A part of the material from the Thames at London is pumped ashore. Research has been mainly focused on the movement of the material in the different rivers and tidal waters. Rarely are pollution measurements conducted in association with dredged material. Turbidity prediction and control do not receive much attention.

43. Some major ports are under the responsibility of a local port authority; the British Transport Docks Board (BTDB) is responsible for the upkeep of several other harbors, of which the harbors along the Humber River and in South Wales are the most important. Special attention will be given to Hull and Cardiff in South Wales. The BTDB has its own research station. Hydraulic model studies as well as prototype measurements are performed, sometimes in connection with dredging activities. The research station has developed a siltmeter, which, by measuring the light transmission, indicates the amount of fine material in suspension in the water. The instrument is used together with current velocity meters to measure the suspended transport. Not much attention has been given by port authorities to pollution because this problem is not yet so serious in the United Kingdom as in some other industrialized countries and because such pollution is mostly considered by other agencies such as:

a. The Institute of Oceanographic Sciences, Taunton.

b. The Council of the Estuarine and Brackish Water Association, Imperial College of Science and Technology, London.

c. Fisheries Laboratory, Lowestoft.

## Cardiff

44. The Port of Cardiff is situated in Wales along the Bristol Channel. It is under the jurisdiction of the BTDB (Figure A16). The tidal range is between 8 and 12 m. The port mainly consists of two nontidal docks with a total quaywall length of about 5 km. In addition to the Port of Cardiff, the local office of BTDB is responsible for four other ports in South Wales, i.e., Newport, Barry, Port Talbot, and Swansea.

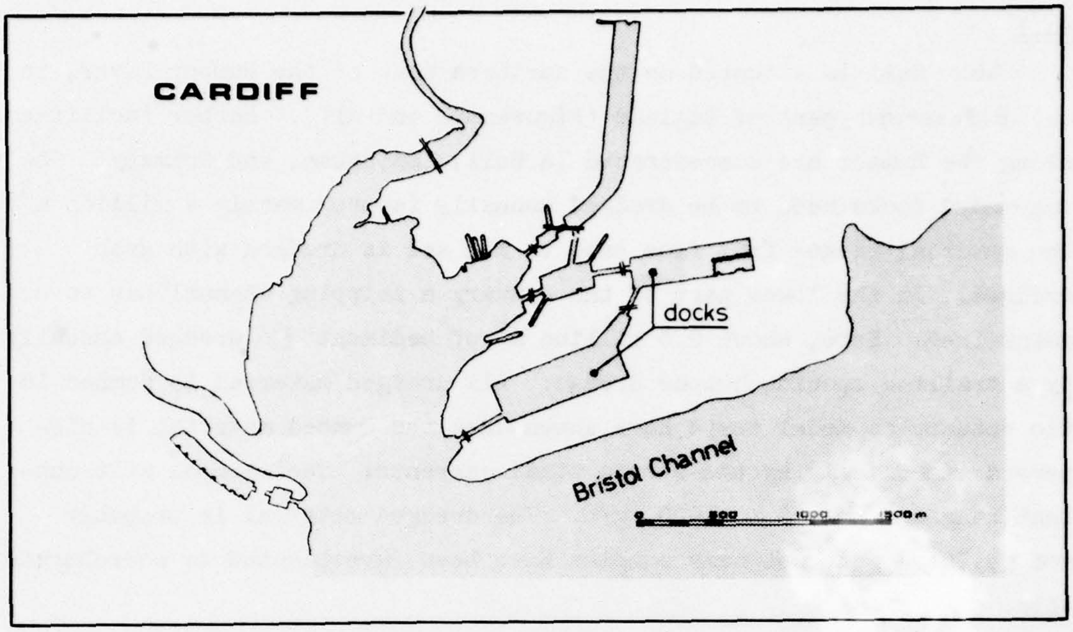



Figure A16. Harbor of Cardiff

45. The annual quantity of maintenance dredging is approximately 4 million $m^3$. No capital dredging has been carried out in the past few years. The material dredged is mainly fine sand and silt; 90 percent of the material is within the limits of 40 and 60 μ. The remaining 10 percent is coarser than 60 μ and occasionally even gravel is present in the bottom material. Soil properties are determined by wet and dry sieving. Dredging is carried out by the port's own equipment: trailing suction hopper dredges are used in the access channel, grab dredges in the harbor basins. All dredged material is dumped at sea in the Bristol Channel. For this dumping a license is issued annually. In connection therewith, the contamination of the dredged material is checked every 3 months. The license is issued with the consent of three ministries:

a. Department of Trade (interest of navigation).

b. Department of the Environment.

c. Department of Agriculture and Fisheries.

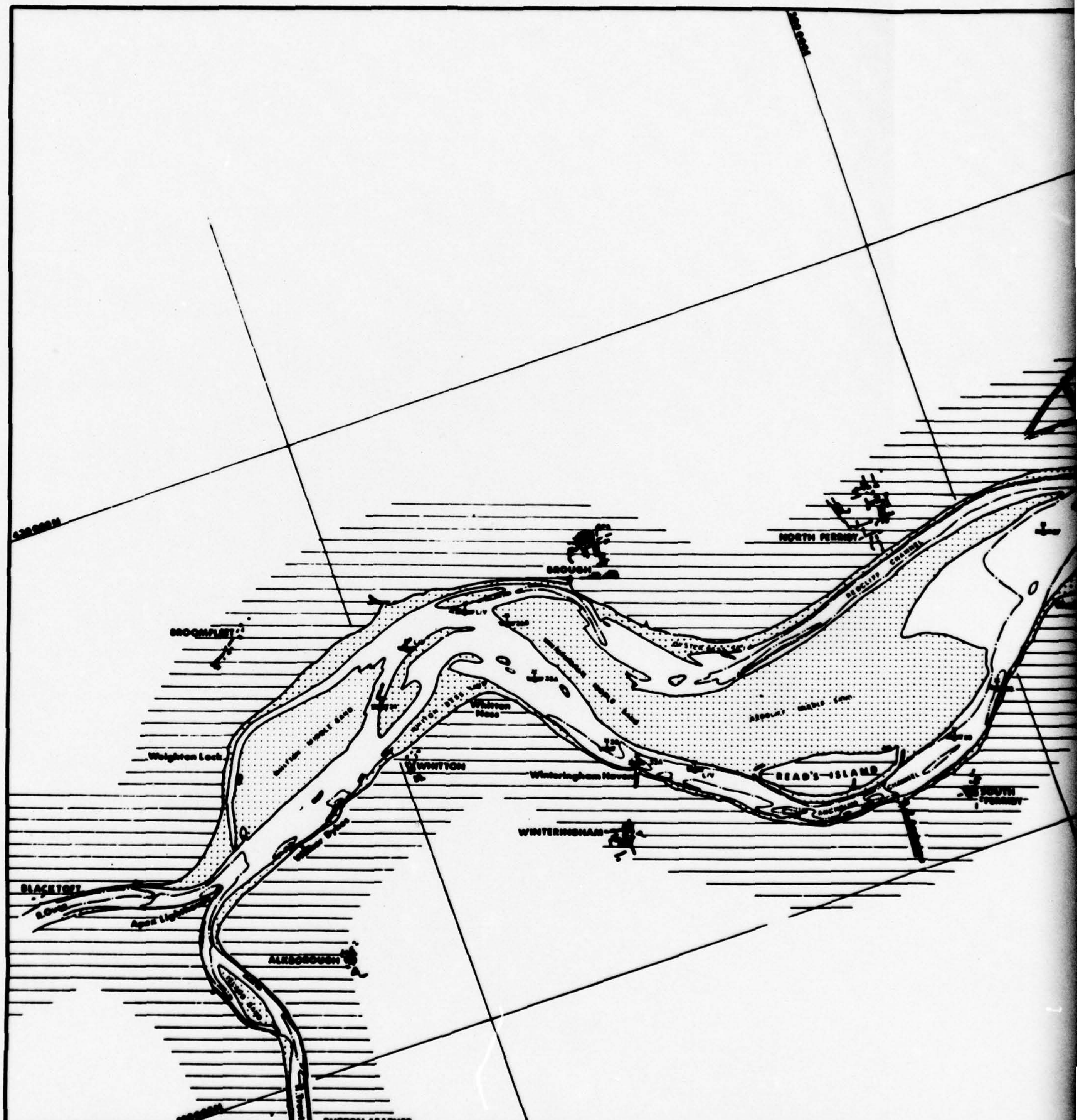
There is no important pollution. Dredge-induced turbidity is no problem in view of the natural silt content of the Bristol Channel, where strong tidal currents bring a lot of material into suspension.

Hull

46. Hull is situated on the northern bank of the Humber River, in the mideastern part of England (Figures A1 and A17). Harbor facilities along the Humber are concentrated in Hull, Immingham, and Grimsby. The impounded docks need to be dredged annually (approximately 4 million $m^3$). The material ranges from fine sand to mud and is dredged with grab dredges. In the lower part of the estuary a shipping channel has to be maintained. Here, about 0.8 million $m^3$ of sediment is dredged annually by a trailing suction hopper dredge. All dredged material is dumped in the estuary as model tests have shown that the dumped material is dispersed immediately by the strong tidal currents. The natural silt content ranges from 300 to 1900 mg/ℓ. The dredged material is probably not polluted, but not many samples have been investigated to corroborate this.

Liverpool

47. Liverpool, in the midwestern part of Great Britain is situated along the Mersey River (Figure A18). It is the second largest port of the United Kingdom. The tidal range varies from 4.5 to 8 m. The dredging can be divided into dredging in the river proper (trailer dredges dredging very fine sand, $3 \times 10^6$ hopper tons per year or 2 million $m^3$ per year) and in the docks (grab dredges dredging mud, $2 \times 10^6$ hopper tons or 1.5 million $m^3$ per year). The transport distance is several kilometres because all the dredged material is dumped at sea. The tidal range and associated current velocities are high. Some of the mud is polluted and some samples have been measured for contaminants (see Part VIII of the main text). The dumping at sea is subject to permission granted by the Ministry of Agriculture, Fisheries and Food, Fisheries Division, Marine Pollution Branch. Scientific investigations were concerned with the best location for the disposal site, which was determined by current measurement and tracers. Work has been done by the University of Liverpool and Wallingford Hydraulics Research Station. Since the Mersey River has a high background turbidity (water velocities up to 4 m/sec), no attention is given to turbidity. The dumping site is surveyed regularly and no accretion has been found.


NORTH FERRIBY
BROUGH
BROOMFLEET
Weighton Lock
WHITTON
Whitton Ness
Winteringham Haven
READ'S ISLAND
WINTERINGHAM
BLACKTOFT
Apex Light
ALKBOROUGH

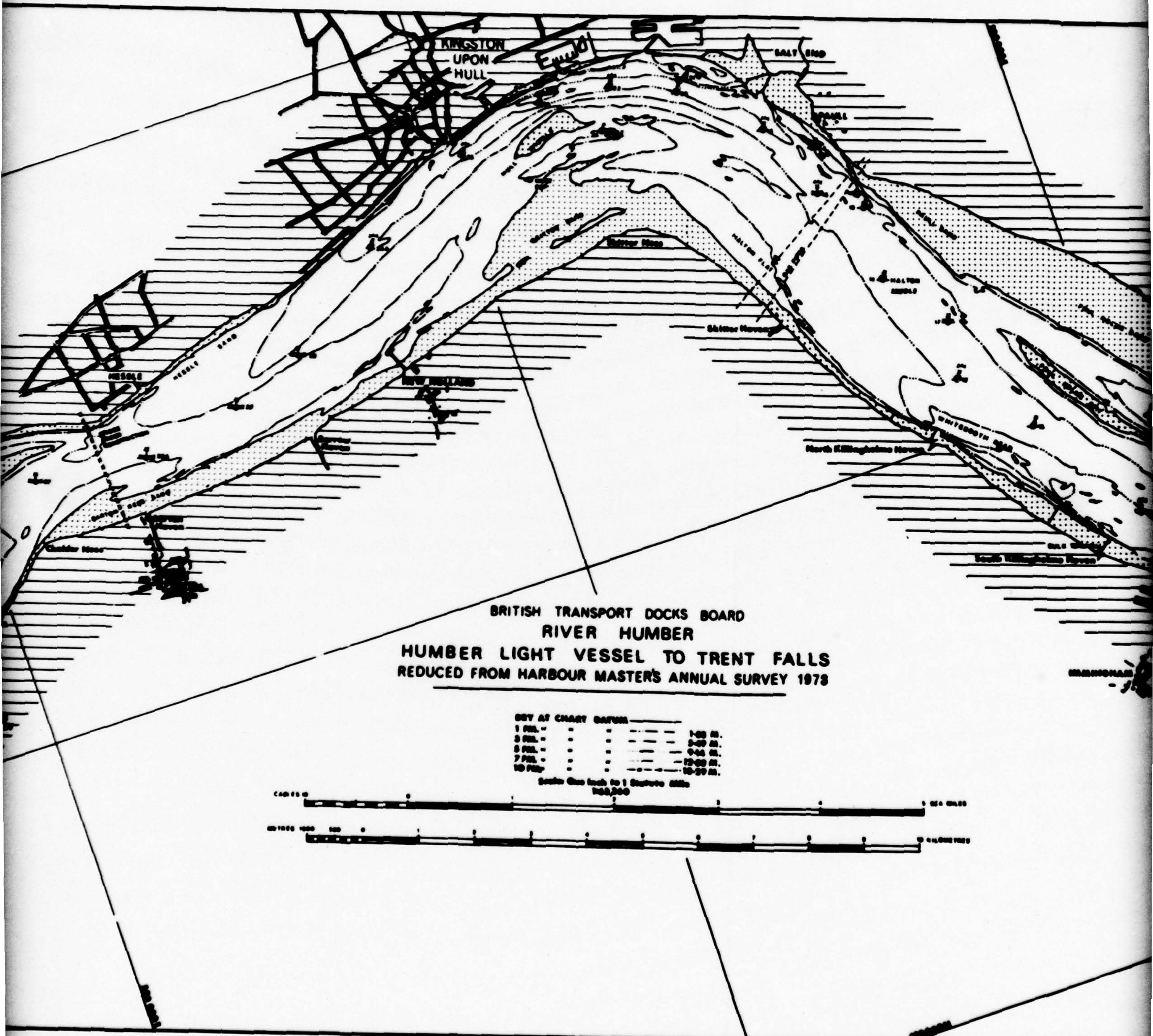
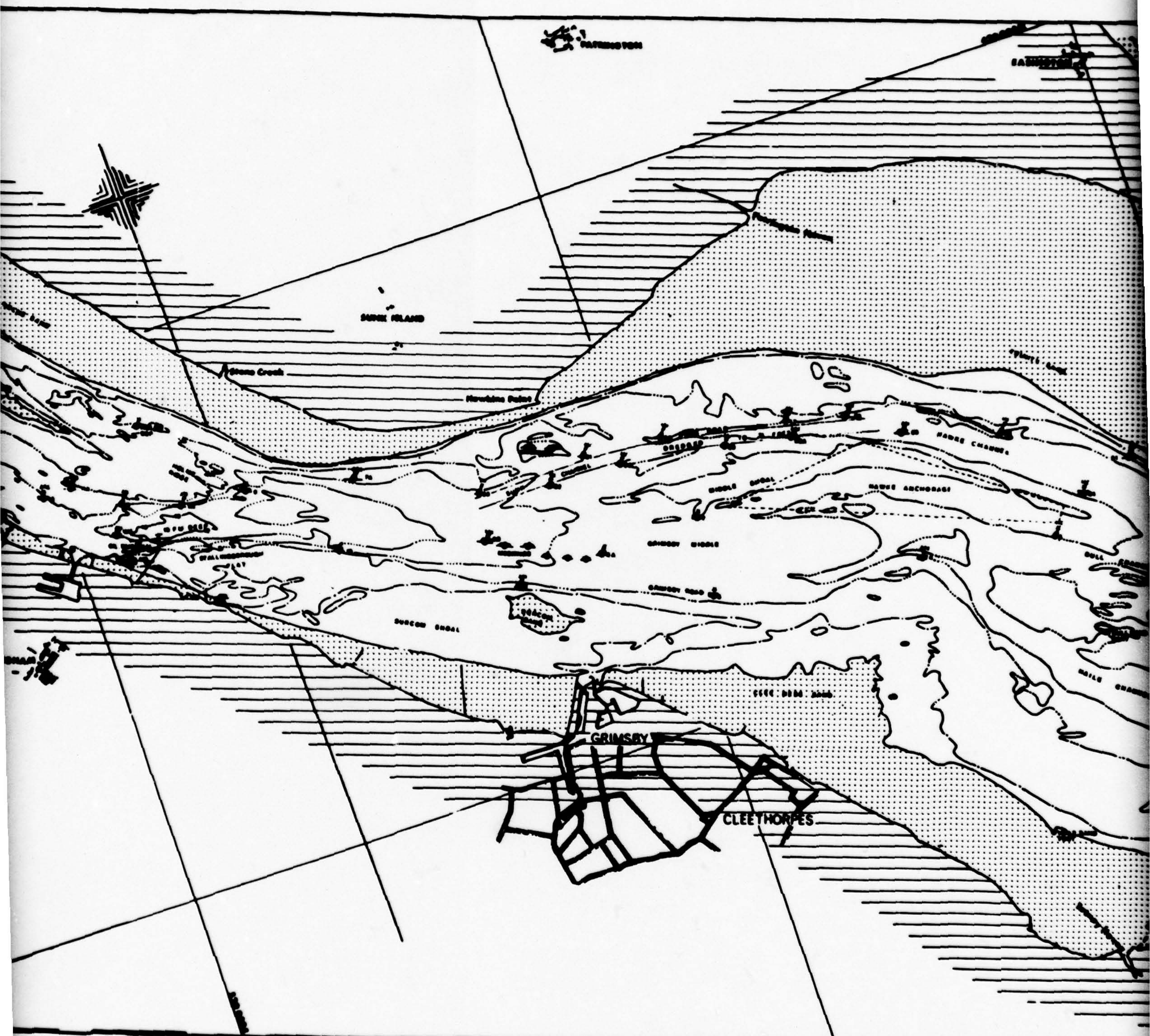
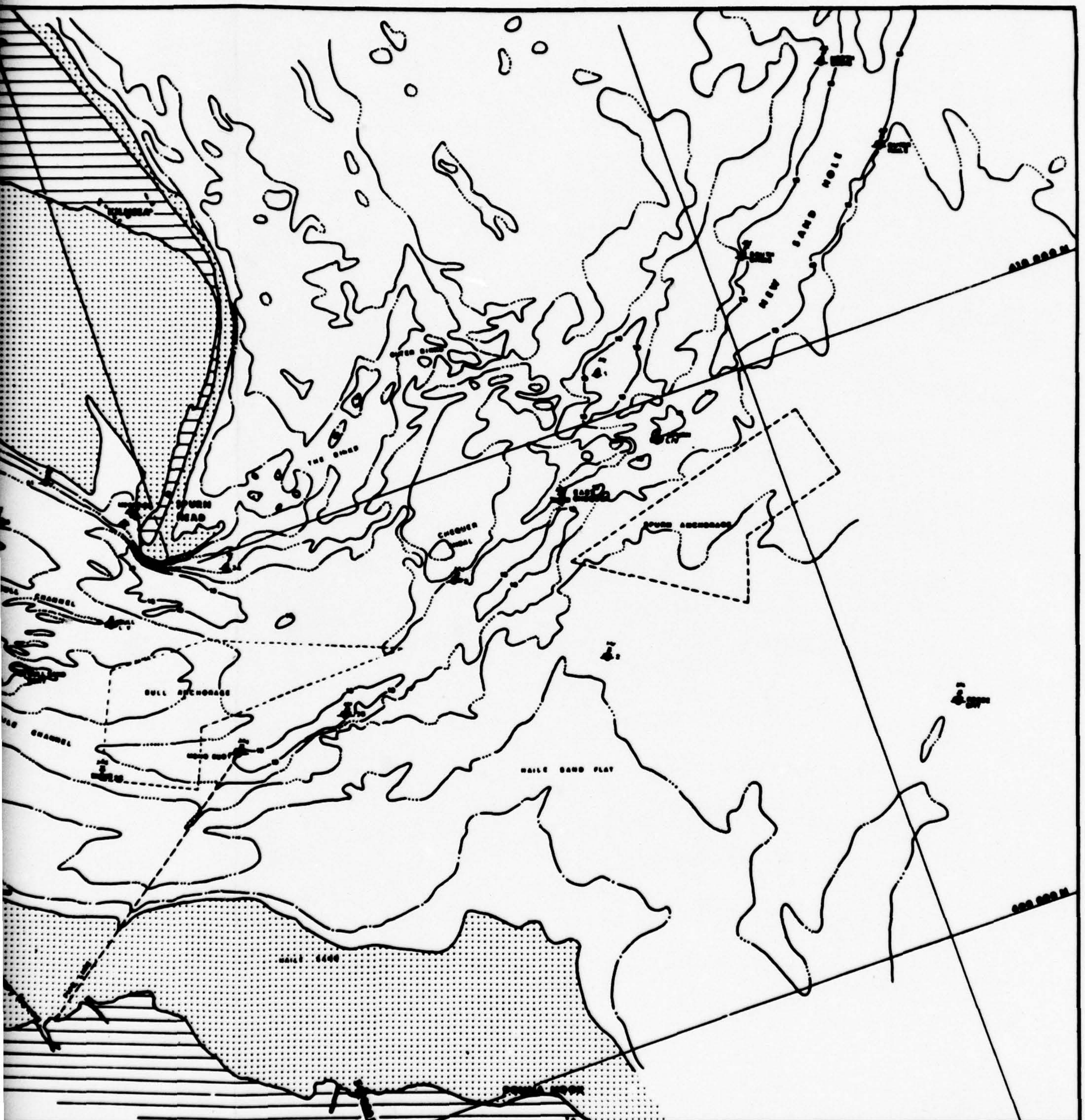



Figure A17. Har




Harbor of Hull

3


NEW SAND HOLE
SPURN ANCHORAGE
BULL ANCHORAGE
HAILE SAND FLAT

3. 4

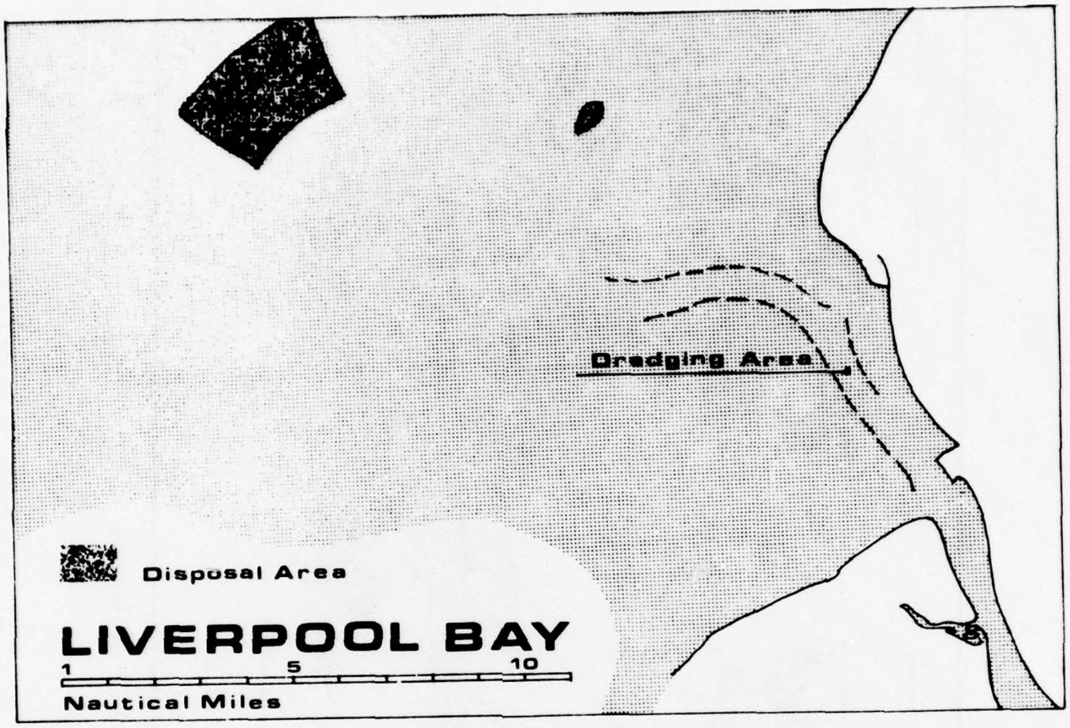



Figure A18. Harbor of Liverpool

London

48. The Port of London comprises the 60 km of tidal Thames River and three enclosed dock systems (Figure A19). The port is under the jurisdiction of the Port of London Authority. Maintenance dredging is concentrated in the entrances of the docks and amounts to 700,000 $m^3$ per year. New work averages 500,000 $m^3$ annually. Most of the maintenance dredging is carried out by the Port Authority. The dredged material from maintenance dredging operations is mainly fine sand with an average grain size ($d_{50}$) of 100 μ, but also contains mud and gravel. With the exception of local oil spills, there is no significant pollution in the Thames estuary. Dredged material is pumped ashore into a disposal area near Rainham. Material is dredged with grab dredges, transported in barges to a reclamation area, and pumped ashore by a reclamation dredge over a distance of about 2.5 km. The disposal area covers 140 ha and is divided in units of about 20 ha. For details on the disposal operations,

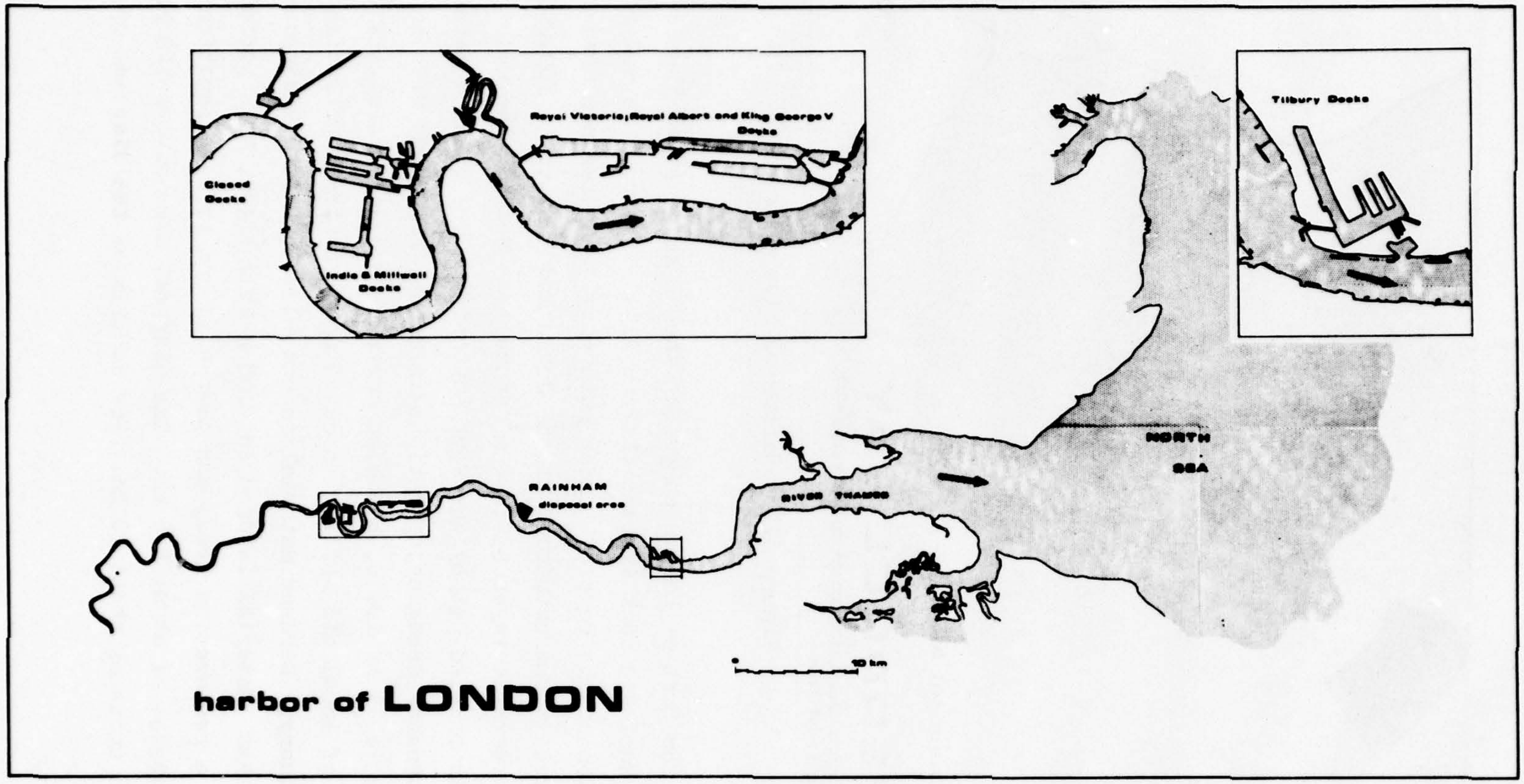



Figure A19. Harbor of London

one is referred to the following notes, made available by the Port of London Authority.

Prior to 1961 all dredgings from the Port of London whether docks or river were transported to the Black Deep dumping ground in the outer Thames Estuary, a distance of 72 miles below London Bridge. Apart from the high cost, analysis of radio-active tracer and other surveys "provided strong evidence that dredgings dumped at Black Deep return to the Estuary, because at both places they indicate a marked landward draft of water and solids at all depths" (C. C. Inglis and F. H. Allen, "The Regimen of the Thames Estuary Affected by Currents, Salinities, and River Flow," Min. Proc. Inst. Civ. Eng., Vol. 7, August 1957). It was therefore decided both on the grounds of economy and for the long term benefit to the regime of the river, to adopt a policy of pumping all suitable dredgings ashore.

Accordingly, a 200-acre site on marshland at Rainham in Essex was developed to receive dredgings and a floating pumping unit was built and moored offshore to handle material from the barges. After 6-1/2 years of use this area was filled to capacity and a new 263-acre site immediately inshore of it was leased to allow the policy of pumping to be continued.

Experience in operating the first site suggested that higher operating efficiency could be achieved by a considerably altered layout and method of operation. The fundamental considerations underlying the design are:

(1) The lagoons must encourage maximum settlement of solids with a consequent minimum return of material to the River.

(2) The deposited material must be capable of drainage and consolidation to acceptable standards.

(3) The deposited material should be evenly distributed over the whole area of the lagoons.

(4) Material for the bund walls must be obtained from within the site. Imported material will reduce its ultimate capacity.

The first of these principles requires that the pumpings shall be retained in the lagoons for a maximum period to allow settlement of the finest fractions and

it is consequently desirable to place the discharge pipe and overflow weirs as far apart as possible. Flow velocities must be kept to a minimum to encourage settlement and prevent "pickup" and "stream-lining" must therefore be avoided. Long, narrow lagoons with a central discharge meet these criteria and offer the greatest prospect of uniform velocities over the whole cross section. "Stream-lining" towards the outlet weirs can only be completely avoided by weirs extending the full width of the lagoons, but their high cost led to a compromise solution of a narrow hard-crested weir comprising moveable boards at each end of each lagoon. When pumping commences, the level builds up slowly behind these weirs to give a depth of water over the mud of approximately 2 ft. In practice, this system gives an effluent whose solid content can be as low as 35 p.p.m., appreciably better than the river water used for dilution.

With the shape of the lagoons determined by considerations of velocities and deposition, their number is determined by the requirement for adequate drainage and consolidation of the deposited material. Experience has shown that effective treatment cannot be carried out on thicknesses in excess of 3 ft and that a period of approximately two years is the order of time required to achieve satisfactory results. It is consequently necessary to devise a cycle of operations which will allow a deposit of dredgings whose thickness is not greater than 3 ft and which will provide a rest period between successive pumpings on the same lagoon of at least 2 years.

Effective drainage and consolidation depends on a number of factors, the most important of which are:

(1) Grain size.

(2) Distribution of material.

(3) Relative positions within the lagoons of inlet and outlets.

(4) Disposal of surface run-off.

(5) Methods used to accelerate drainage.

The type of material deposited is only size-controlled by the capability of the pump and is mostly fine silt with some sand and a small proportion of ballast. As might be expected, the heavier materials deposit close to the inlet, whilst finer silts accumulate nearer the weirs. In addition, the surface levels tend to be higher nearer the inlet and with this central to the

lagoons, good natural drainage towards the weirs is created. Even distribution over the lagoons can be encouraged if necessary by closing alternately the weirs at each end and directing the flow towards the closed weir.

The marshland site for the disposal area has a limited thickness of soft clay overlying peat. Only this surface clay is considered suitable for constructing the bund walls and in view of the restricted quantity available and to avoid the high cost of importing material, it was decided to raise the bunds in stages using deposited material for each lift after the initial one. It is consequently essential to ensure maximum drainage so that earth moving plant can operate on the filled areas. The side slopes of the bund walls were fixed at 1:2-1/2 to cater for the low stability of both the clay and dredged materials.

The pumping is carried out by 2 Gwynnes dredge pumps powered by 935 hp British Polar 2-stroke engines. Diluting pumps are Gwynnes powered by 320 hp Crossley engines and are capable of delivering 16,000 gpm. Delivery to the lagoons is by 27 ins. internal diameter steel pipeline whose ultimate length will be the order of 8,000 ft. For pumping to the original lagoons and during the early stages of the present site, the pumps have been used singly, but it is intended to use them in series as the pipeline is extended. A minimum clearance of 15 ft. 6 in. was required where the pipeline crossed the road bordering the site and it was decided to continue the pipeline at this level to avoid subsequent raising as the lagoons are filled. To carry the pipe part of the way the most easterly bund was constructed to its full height at the outset. Where the pipe crosses the lagoons, to provide a central discharge, it is carried on trestles.

The original marsh level was approximately 1.5 m ODN* (5 ft approximately) and the final level of dredgings deposited in the first two lagoons (A and B) is approximately 6.2 m ODN (18.9 ft approximately). The maximum height of the bunds and deposited dredgings in lagoons 1 to 7 is restricted to 6.2 m ODN (18.9 ft approximately) and it is anticipated there is sufficient capacity left in these seven lagoons to accept P.L.A. dredgings until 1980 at the present rate of pumping.

---

* ODN Ordinance Datum.

There is a contract in operation between the P.L.A. and a G.L.C. Refuse Disposal Contractor whereby unprocessed London refuse, hauled down by river to Coldharbour Point, is being deposited in lagoon B, the final height of which deposit will be approximately 8.8 m ODN (29 ft approx.).

When the present P.L.A. operations in lagoon A near the river are complete, the intention is that the refuse disposal contract will be extended to incorporate lagoon A to the same levels of deposition. This refuse disposal contract incorporates a Clause for finishing off at the 8.8 m ODN level with approximately 0.6 m of earth to provide adequate cover of the refuse from erosion and pollution nuisance, as well as allowing normal vegetation to develop quickly.

Lagoons 1 to 7 on the Ministry of Defence land, leased to the P.L.A. at present, will be finished off with a grassed levelled surface.

Due to large settlement that will continue in the areas on both sets of lagoons, the only possible 'after-use' will be as grazing land or recreational land.

# APPENDIX B: CLASSIFICATION OF SOILS FOR DREDGING PURPOSES*

Table B1. General Basis for Identification and Classification of Soils[1] for Dredging Purposes

| Main Soil Type | | Particle size identification: Range of size (mm) | Particle size identification: B.S. Sieve (2) | Identification | Strength and Structural Characteristics |
|---|---|---|---|---|---|
| Boulders<br>Cobbles | GRANULAR (non-cohesive) | Larger than 200 mm<br>Between 200-60 mm | (6) | Visual examination and measurement | N.A. |
| Gravels | GRANULAR (non-cohesive) | Coarse 60-20<br>Medium 20-6<br>Fine 6-2 mm | 3" - ¾"<br>¾" - ¼"<br>¼" - No. 7 | Easily identifiable by visual examination | Possible to find cemented beds of gravel which resemble weak conglomerate rock. Hard-packed gravels may exist intermixed with sand. |
| Sands (3) | GRANULAR (non-cohesive) | Coarse 2-0.6<br>Medium 0.6-0.2<br>Fine 0.2-0.06 mm | 7 - 25<br>25 - 72<br>72 - 200 | All particles visible to the naked eye. Very little cohesion when dry. | Deposits will vary in strength (packing) between loose, compact and cemented. Structure may be homogeneous or stratified. Intermixture with silt or clay may produce hard-packed sands. |
| Silts (3) | COHESIVE | Coarse 0.06-0.02<br>Medium 0.02-0.006<br>Fine 0.006-0.002 mm | Passing No. 200 | Generally particles are invisible and only grains of a coarse silt may just be seen with naked eye. Best determination is to test for dilatency (4). Material may have some plasticity, but silt can easily be dusted off fingers after drying and dry lumps powdered by finger pressure. | Essentially non-plastic but characteristics may be similar to sands if predominantly coarse or sandy in nature. If finer will approximate to clay with plastic character. Very often intermixed or interleaved with fine sands or clays. May be homogeneous or stratified. The consistence may vary from fluid silt through stiff silt onto "siltstone". |
| Clays | COHESIVE | Below 0.002 mm<br>Distinction between silt and clay should not be based on particle size alone since the more important physical properties of silt and clay are only related indirectly to particle size. | N.A. | Clay exhibits strong cohesion and plasticity, without dilatency. Moist sample sticks to fingers, and has a smooth, greasy touch. Dry lumps do not powder, shrinking and cracking during drying process with high dry strength. | Strength — Shear Strength (5)<br>V. Soft: May be squeezed easily between fingers. — Less 0.17 kgr/cm²<br>Soft: Easily moulded by fingers. — 0.17-0.45 "<br>Firm: Requires strong pressure to mould by fingers. — 0.45-0.90 "<br>Stiff: Cannot be moulded by fingers, indented by thumb. — 0.90-1.34 "<br>Hard: Tough, indented with difficulty by thumb nail — Above 1.34 kg/cm²<br>Structure may be fissured, intact, homogeneous, stratified or weathered. |
| Peats and Organic soils | ORGANIC | N.A. | N.A. | Generally identified by black or brown colour, often with strong organic smell, presence of fibrous or woody material. | May be firm or spongy in nature. Strength may vary considerably in horizontal and vertical directions. |

Notes: N.A.: Not Applicable.

(1) Soil may be defined in the engineering sense as any naturally occurring loose or soft deposit forming part of the earth's crust. The term should not be confused with "pedological soil" which includes only the topsoil capable of supporting plant growth, as considered in agriculture.

(2) Or National equivalent sieve size/no.

(3) There may be some justification for including a range of "extra fine" sand and "extra coarse" silt over the particle size ranges (0.1-0.06 mm) and (0.06-0.04 mm) respectively. It is recommended that whenever possible in borehole description or verbal discussion such further identification of these soils should be used. However, to avoid the chance of confusion, if the classification "fine" sand or "coarse" silt is used without further qualification, it will be taken that the particle size ranges fall within those given in Table 1 above.

(4) Dilatency is the property exhibited by silt as a reaction to shaking due to the higher permeability of silt. If a moistened sample is placed in the open hand and shaken, water will appear on the surface of the sample giving a glossy appearance. A plastic clay gives no reaction.

(5) Defined as the undrained (or immediate) shear strength ascertained by the applicable in situ or laboratory test procedure.

(6) Though only visual examination and measurement are possible an indication should be given with respect to the size of the "grains" as well as to the percentages of the different sizes.

* Taken from PIANC Bulletin, 1972, No. 11.

Table B2. Classification of Soils for Dredging Purposes by In Situ and Laboratory Testing

| Main Soil Type | | Particle Size Distribution | In situ density or Bulk Density (1) | Specific gravity of the solid particles (1) | Compactness (in situ) | Moisture content | Plasticity | Shear Strength | Lime content | Organic content |
|---|---|---|---|---|---|---|---|---|---|---|
| Boulders Cobbles | GRANULAR (non cohesive) | Visual in field | N.A. | Lab. test (on fragments) | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| Gravel | GRANULAR (non cohesive) | Lab. test | N.A. | Lab. test | In situ test | N.A. | N.A. | N.A. | N.A. | N.A. |
| Sands | GRANULAR (non cohesive) | Lab. test | Lab. test on undisturbed samples | Lab. test | In situ test | Lab. test | N.A. | N.A. | Lab. test | Lab. test |
| Silts | COHESIVE | Lab. test | Lab. test on undisturbed samples | Lab. test | In situ test or lab. test on undisturbed samples | Lab. test | Lab. test | Lab. test | Lab. test | Lab. test |
| Clays | COHESIVE | N.A. | Lab. test on undisturbed samples | N.A. | In situ test or lab. test on undisturbed samples | Lab. test | Lab. test | Lab. test | N.A. | Lab. test |
| Peats and organic soils | ORGANIC | N.A. | Lab. test on undisturbed samples | N.A. | In situ test | Lab. test | Lab. test | Lab. test | N.A. | Lab. test |

Notes: N.A.: Not applicable

Tests double outlined are considered to be of priority for assessment of soil characteristics for dredging purposes.

(1) For definitions see Table 3.

Table B3. In Situ and Laboratory Testing Procedures of Soils

| Soil Properties or Characteristics | In situ Test | Laboratory Test (site or central laboratory) | References (*) (British Standards or equivalent) |
|---|---|---|---|
| Particle size analysis | N.A. | Sieving on granular soils. Sedimentation on cohesive soils. Combination on mixed soils such as sandy clays.<br>A rough evaluation by comparison with standard soil samples, by microscope or with grid counter. | B.S. 1377 (1967) p. 55 |
| Bulk density or in situ density | N.A. except for measurement of boulders and cobbles | The unit weight of soil as found in situ and expressed as the ratio between total weight and total volume of soil. | For definitions :<br>"Technical terms, symbols and definitions" I.S.S.M.F.E. (1968) p. 88 and 89. |
| Specific gravity of the solid particles | N.A. | S.G. determined as the ratio between unit weight of solid particles and unit weight of water. | B.S. 1377 (1967) p. 40 |
| Compactness (in situ) | May employ several insitu tests, e.g.<br>(i) Standard penetration test<br>(ii) Dutch penetrometer (sounding)<br>(iii) Swedish penetrometer<br>(iv) French penetrometer etc. | N.A. | (i) Foundation Engineering (Peck, R.B., Hanson, W.E. and Thornburn, T.H.) Chapman & Hall, London (1953).<br>(ii), (iii), (iv) Le Pénétromètre et la Reconnaissance des Sols (Sanglerat), Dunod, Paris (1965). |
| Moisture Content | (i) Can employ "Speedy" moisture content tests on site but not recommended<br>(ii) Radio-active meter method | (iii) Moisture content determination. | (i) Equipment manufactured by Thomas Ashworth & Co. Ltd., Burnley, Lancs., U.K.<br>(ii) Meigh, A.C. and Skipp, B.O. - "Gamma-ray and neutron Methods of measuring soil density and moisture.<br>Geotechnique, X (1960), 3 June pp. 110-126.<br>(iii) B.S. 1377 (1967) p. 25 |
| Plasticity | N.A. | Determination of Liquid and Plastic Limits (Atterberg test) | B.S. 1377 (1967) p. 33 |
| Shear strength | May employ several in situ tests, e.g.<br>(i) Hand Penetrometer<br>(ii) Vane Tests<br>(iii) Dutch penetrometer (sounding)<br>(iv) Swedish penetrometer<br>(v) French penetrometer, etc. | (i) Torvane<br>(vi) Hand penetrometer<br>(vii) Unconfined Compression apparatus<br>(viii) Triaxial Compression<br>(ix) Cell apparatus<br>(x) Fall cone<br>etc. | (i) Item manufactured by "Soiltest" Inc., Evanston, Ill., U.S.A.<br>(ii) Geotechnique Vol. I, p. III (Skempton, A.W.) The Institution of Civil Engineers, London (1948).<br>(iii), (iv), (v) See reference given above for "compactness"<br>(vi) See reference given above<br>(vii) Soil Mechanics for Road Engineers (D.S.I.R.) H.M. Stationery Office London (1964) p. 369 et seq.<br>(viii) Soil Mechanics for Road Engineers (D.S.I.R.) H.M. Stationery Office London (1964) p. 361 et seq., or for more advanced study:<br>The measurement of soil properties in the Triaxial Test (Bishop, A.W. & Henkel, D.J.) Arnold London (1962)<br>(ix) Geuze, E.C.W.A. and Tan Tjong Kie "The shearing properties of Soils"<br>Part I: The cell-test procedure<br>Part II: Comparison of triaxial and cell-test results<br>Geotechnique II (1950), 2 December, pages 141-261.<br>(x) A new approach to the determination Shear Strength of clay by the Fall cone test (Hansbo) Royal Swedish Geotech. Inst. Stockholm (1957). |
| Lime content | N.A. | Visual test for effervescence when cold dilute hydrochloric acid (HCl) is applied to specimen | |
| Organic content | N.A. | Determination of organic content | B.S. 1377 (1967) p. 86 |

N.A.: Not Applicable

(*) It should be emphasized that other international or national references exist. It is the intention to obtain information on the relation (for example) between the appropriate national standards (e.g. B.S., DIN, A.S.T.M., etc...) and give this information in later editions of the P.I.A.N.C. Bulletin.

Table B4. General Basis for Identification and Classification of Rocks[1] for Dredging Purposes

| Group | Examples of Rock Type | Origin | Identification | Remarks |
|---|---|---|---|---|
| I. Igneous | Granites<br>Dolerites<br>Basalts<br>etc. | Formed by the solidification (crystallisation) of original molten material (magma) extruded from within the earth's crust. | All exhibit a crystalline form although the individual crystals may be invisible to the naked eye. Complex system of rocks. All igneous rocks are hard although may be altered by various natural causes such as weathering. Because of stress rocks may possess systems of joints and fissures. | Full identification of rocks may be complex. Hand examination will give approximate classification based on rock type name. Laboratory examination may be required using rock slices to confirm the more difficult cases.<br><br>Engineering properties of rock for dredging purposes requires generally to be carried out in laboratory using Test Procedures suggested in Table 5.<br><br>Whilst for practical purposes it may not be necessary to identify a rock by name it is of inestimable value in analysing the project as a whole.<br><br>Degree of weathering in rock is of extreme importance and will alter the engineering properties of even the hardest igneous rocks. |
| II. Sedimentary | Sandstone<br>Limestones<br>Marls<br>Chalk<br>Corals<br>Conglomerates<br>etc. | Derived from pre-existing formations by weathering and disintegration, often being reconsolidated in hard strata. Occurring as sequence of deposits in beds. | Often recognisable by bedded structure. In general terms the older the formation, the harder the rock although a considerable variation in hardness, colour and other characteristics is likely. In many sedimentary rocks the individual particles forming the body of the material may be seen (e.g. sandstone) and a rough grading given in description. | |
| III. Metamorphic | Gneisses<br>Marbles<br>etc. | Includes an igneous or sedimentary rock which has been altered by heat or pressure. | Wide range in degree of metamorphism with some rocks still close to original condition, other rocks completely recrystallised so that original structure obscured. Rock is normally very-hard with glassy surface. | |

Notes: (1) Rock may be defined in the engineering sense as the hard and rigid deposits forming part of the earth's crust as opposed to deposits classed as soil. Geological rock embraces both soft and hard naturally occurring deposits, excluding topsoil.

Table B5. Classification of Rocks for Dredging Purposes by Field and Laboratory Testing

| Group | Example of Rock | Bulk Density | Porosity | Surface Hardness | Uniaxial compression strength | Dynamic penetration | Drillability | Cementation |
|---|---|---|---|---|---|---|---|---|
| I. Igneous | Granites Basalts etc. | Lab. test | N.A. unless weathered | Lab. test | Lab. test | N.A. unless weathered | Field test | N.A. unless weathered |
| II. Sedimentary | Sandstones Limestones etc. | Lab. test | Lab. test | Lab. test | Lab. test | Field test; particularly applicable to corals | Field test- | Lab. test |
| III. Meta-morphic | Gneisses Marbles etc. | Lab. test | N.A. unless weathered | Lab. test | Lab. test | N.A. unless weathered | Field test | N.A. unless weathered |

Note: Rocks may be subjected to various other more complex tests now in use in rock mechanics analyses. However, while such testing procedure may be of interest to the research worker, they appear to have little application at the present time for appreciation of the practical problems involved in tendering and programming dredging projects.

Table B6. Testing Procedures of Rocks

| Rock Property or Characteristics | In situ Test | Laboratory Test | Reference (*) |
|---|---|---|---|
| Bulk density | N.A. | Volume/weight relationship | |
| Porosity | N.A. | Measure of pore space expressed as percentage ratio voids/total volume | Porosity value may be obtained in similar manner to the test for water absorption given in B.S. 812 (1967) p. 39 et seq. |
| Surface Hardness | N.A. | Moh's surface hardness scale graded from O (Talc) to 10 (Diamond) | Sets of representative minerals in Moh's scale are obtainable commercially through suppliers of minerals and geological equipment. |
| Uniaxial Compression Strength | N.A. | Test to obtain direct measure of stress at ultimate failure under compressive load. The dimensions of the testpiece and the direction of stratification relevant to the stress-direction are to be stated. | B.S. 812 (1967) p. 82 (but note that present practice is to prefer length/diameter ratio of 2:1) |
| Dynamic penetration | Particularly applicable to corals: Standard penetration test | N.A. | See table 3. |
| Cementation | N.A. | Relative measure of strength of bond between rock constituents. Assessed visually by soaking specimen in water. | |
| Drillability | Measurement to be made during drilling operations. Note speed of drilling together with drill specification (size, H.P., etc.). A special note should be made of percentage core recovery for each drill run | N.A. | |

N.A.: Not Applicable.

(*) It should be emphasised that other international or national references exist. It is the intention to obtain information on the relation (for example) between the appropriate national standards (e.g. B.S., DIN, A.S.T.M., etc...) and give this information in later editions of the P.I.A.N.C. Bulletin.

Table B7. Sampling and Investigation Procedures for Dredging Purposes

| Rock or Soil Type | Core Rotary Drilling (diamond drilling) | Mud Rotary Drilling | Shell & Auger Boring | Hand Auger or Hand Auger Tube | Static Penetration test (e.g. Dutch, Swedish) | Wash Borings | Undisturbed (1) Sampling | Disturbed (1) Representative Samples | Dynamic penetration tests (2) | In situ Vane Testing | Geophysical Methods |
|---|---|---|---|---|---|---|---|---|---|---|---|
| I. Igneous rock II. Sedimentary rock III. Metamorphic rock | Best method of obtaining core samples of intact rocks in in situ conditions for examination and test | Method of drilling using medium (fluid) to support side of hole. Not recommended for site investigation | N.A. | N.A. | N.A. | N.A. | Core samples or large fragments represent undisturbed samples | Fragments may be used for identification | See Tables 5 and 6 | N.A. | |
| Boulders Cobbles | May be used to penetrate and obtain core samples | N.A. | Chiselling required to penetrate strata | N.A. | N.A. | N.A. | Cobbles retained as undisturbed samples | N.A. | N.A. | N.A. | Useful method of site investigation for "filling in" detail between borings and drillings. However, note should be taken that such methods still require improvement and very careful interpretation. Necessary to have relatively simple soil/rock conditions for success with this method (i.e. soft alluvium over rock). Where only slight changes in strata density occur method is doubtful and may be misleading |
| Gravels | N.A. | N.A. | Method employed for site investigation in order to obtain representative & undisturbed samples and to carry out field (in situ) tests. Popular in U.K. Borehole sizes of 6" and 8" dia. | N.A. | Very difficult to penetrate coarse gravel | Difficult to penetrate | Not practicable to retain gravel as an undisturbed sample unless in cemented condition | Obtained from borings in tins or bags. Must be "representative" (i.e. only from a single horizon or stratum). Essential for identification of various strata, cheapest samples | Used with some given reasonable in situ compactness | N.A. | |
| Sands | N.A. | N.A. | | Difficult method may locate top of hard stratum | Useful method for determining in situ properties and "hard" strata levels. In areas with wide soil variation may be useful to supplement borehole information. | Not recommended for site investigation except to determine the level of a "hard" stratum beneath softer materials | Patent samplers available, difficult to sample in undisturbed condition | | Useful for in situ compactness estimate at the same time a sample is obtained | N.A. | |
| Silts | N.A. | N.A. | | Possible method if material is soft or will stand without sides caving. Rather slow | | | If cohesive in nature can use clay undisturbed core samplers, otherwise see Sands | | Can very well be used, but interpret with care | Used for estimate of shear strength but great care needed in interpretation | |
| Clays | N.A. | N.A. | | | | | Variety of undisturbed core samplers available | | | Very useful for shear strength evaluation in alluvial clays | |
| Peats, etc. | N.A. | N.A. | | Useful for "locating hard stratum beneath peat | | | Variety of undisturbed core samplers available | | | Used for estimate of shear strength but great care needed in interpretation | |

Notes: N.A.: Not Applicable

(1 Care should be observed in handling and preserving samples. Samples of rock should be retained where possible in conditions approximating to in situ state. Undisturbed and disturbed samples of soil, particularly core samples of cohesive materials, should be protected from loss of natural moisture. Great care in labelling samples is of paramount importance.

(2 Reference is for the "Standard Penetration Test" previously termed the ("Raymond Penetration Test"). Review of other dynamic tests is given in Geotechnique Vol. XVIII p. 98. The Institution of Civil Engineers, London (1968); see also Table 3.

Test dredging. - There may be some projects on which the complexity of the soil or rock or other special circumstances warrant the use of test dredging or even make test-dredging desirable. In other cases (as channel widening) results of previous dredging contracts might be used. In both cases full details with respect to all relevant circumstances should be provided, including quantitative and qualitative examination of the spoil & description of the dredger used. Great care should be taken by the principal in providing exact and reliable information and by the contractor in interpreting this information.

Table B8. General Characteristics of Soils and Rocks for Dredging Purposes

(Rocks Unweathered* and Unblasted)

| Rock/Soil Type | Excavation Characteristics | | | | | | Suitable as reclamation material | Suitability to pipeline transportation | Often observed bulk density before excavation |
|---|---|---|---|---|---|---|---|---|---|
| | Dipper dredger | Bucket dredger | Suction dredger | Cutter dredger | Trailer dredger | Grab dredger | | | |
| **ROCK*** | | | | | | | | | |
| I. Igneous | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | 2.0 -2.8 |
| II. Sedimentary | Possible in soft rock but difficult | Possible in soft rock but difficult | N.A. | Difficult to fair in softer rocks | N.A. | Possible in softer rocks but very difficult | Very good | Fair, large fragments may block pipes | 1.9 -2.5 |
| III. Metamorphic | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | 2.0 -2.8 |
| * Weathering of rocks will alter form and strength considerably and may allow direct dredging without blasting, etc. | | | | | | | | | |
| Boulders | Fair | Very slow, may require slinging | N.A. | N.A. | N.A. | Difficult but large units cope | Not acceptable | N.A. | N.A. |
| Cobbles or Cobbles with gravel | Fair | Fair | Difficult | Difficult | Difficult | Fair | Bad to Good | Poor | N.A. |
| Gravel | Easy | Fair | Difficult to Fair | Fair | Difficult to Fair | Fair | Good | Fair | 1.75-2.2 |
| Sandy gravel | Easy | Fair to Easy | Fair | Fair to Easy | Fair to Easy | Fair to Easy | Very good | Fair to good | 2.0 -2.3 |
| Medium sand<br>Fine sand<br>Extra Fine Sand<br>Silty Fine Sand | Easy but low production | Easy | Easy<br>Fair | Easy | Fair to Easy but high over-flow losses likely | Easy | Very good<br>Good | Good<br>Very good | 1.7 -2.3 |
| Cemented fine sand | Fair | Fair | N.A. | Fair to Easy | Difficult | Difficult | Good | Bad to good | 1.7 -2.3 |
| Silt | N.A. | Easy | Difficult to Fair | Easy | Fair to Easy but high overflow losses | Fair | Bad | Very good | 1.6 -2.0 |
| Firm or stiff gravelly or sandy clays (i.e. boulder clays) | Fair | Difficult to Fair | N.A. | Difficult to Fair | N.A. | Difficult to Fair | Good | Only possible after desintegration | 1.8 -2.4 |
| Soft silty clays (i.e. alluvial clays) | N.A. | Fair to Easy | N.A. | Easy | Fair | Easy | Bad | Fair | 1.2 -1.8 (fresh harbour sediment 1.15-1.6) |
| Firm or stiff Silty clays | Fair to Easy | Easy | N.A. | Fair to Easy | Difficult to Fair | Fair | Bad to fair | Only possible after desintegration | 1.5 2.1 |
| Peats | N.A. | Easy | N.A. | Easy if no gas encountered | Fair | Easy | Unacceptable | Very good | 0.9 -1.7 |

N.A. : Not Applicable.

Note: This table only gives a *rough indication* and should *be used with caution*.

The feasability to use a certain type of dredging equipment depends not only on the soil type, but also on site conditions, the size, strength of construction and power supply of that piece of equipment, etc.

The qualifications used above (i.e. bad, poor, fair, easy, very good, etc.) are meant to show the degree of suitability but should not be related to the output or even less as indicative *on the cost per excavated unit*.

APPENDIX C: THE USE OF POLYMERS

1. A biocolloid polymer (1 percent) was added to different clay-water mixtures. The settlement of the mud column was accelerated about 100 times because of flocculation (see Figure C1). It was found, however, that with increasing concentration the acceleration effect diminished. If the specific weight of the mud was over 1.10, the influence of the polymer was negligible.

2. Small-scale tests were performed on filling a hopper with a clay-water mixture with a polymer additive. The dimensions of the surface of the hopper were 1.2 × 0.6 m. The discharge varied from $4 \times 10^{-3}$ to $3 \times 10^{-3}$ $m^3/sec$. The specific weight of the mud varied from 1.02 to 1.16. There was no evidence of a systematic higher density in the hopper than in the overflow.

3. The use of a cyclone did not improve matters. The poor result is attributed to the destruction of the flocs because of the turbulence in the system and/or the shearing forces in the hydrocyclone.

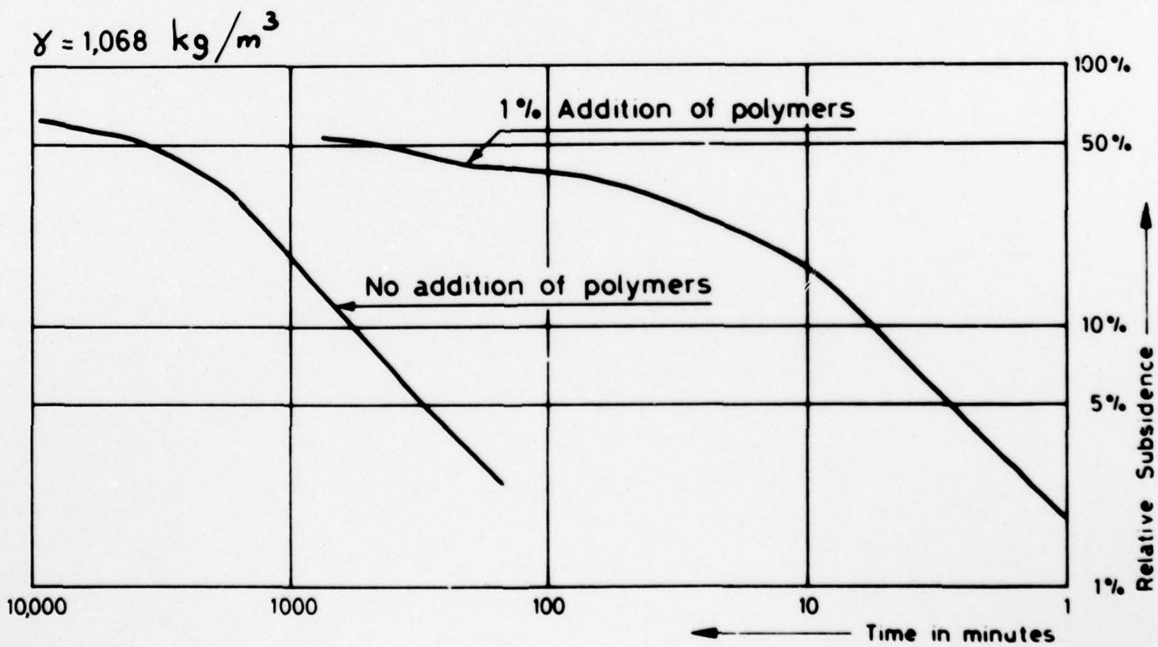



Figure C1. Effect of polymer addition

## APPENDIX D: DEHYDRATION OF CLAY MINERALS

**by J.R. Willet, Adviesbureau Arnhem bv.**

### 1. Clay minerals, their origin and composition

Clay minerals are alteration products of other minerals, the so-called weathering products.
They may orininate in site through chemical and physical changes, or somewhere else and far away through eroded or diluted products. The larger part of soil particles smaller than 2 micrometer (the so-called clay frastion) consists of clay minerals.

From a chemical point of view clay minerals are water- and (OH)- holding aluminium silicates.

Five groups are generally distinguished: four have a laminated and the fifth an amphibolic (band-like) stwucture

1. kandite-group : kaolinite, halloysite, and others.
2. Illite-group : hydromica, illite, glauconite, a.o.
3. Smectite-group: montmorillonite, beidellite, a.o.
4. vermiculite-group : vermiculite
5. palygorskite-group: sepiolite, palygorskite

The mineralogical structure of kaolinite and montmorillonite is illustrated in figure D1.

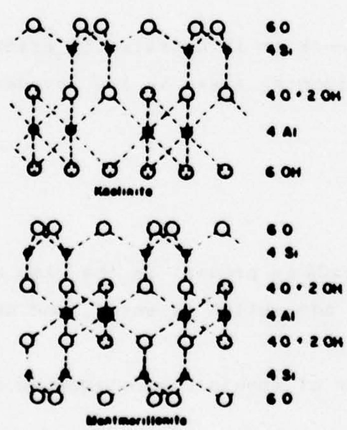



Figure D1. Schematic representation of the structure of aluminosilicate minerals

(after Hillil, 1971, p.19, fig.15)

In soil studies we have often to do with the following clay minerals:

kaolinite, specific for red and yellow soils of the torrid zone

halloysite, specific for weathering products of calcareous rocks in the torrid zone.

illite: specific for most clays in the temperate zone.

montmorillonite, specific for black and gray soils in the torrid zone.

Mohr and van Baren (1954) made a review of weathering theories, explaining the origin of various clay minerals.

Some factors seem to have an effect namely

1. the mother rock
2. the chemical conditions of soil solution (pH, kind and concentration of cations, $SiO_2/Al_2O_3$- ratio).
3. the climate
4. the topography and the drainage conditions.

It is widely admitted (though still discussed) that soils of the kaolinite type (latosoils or lateritic soils) come into being under the influence of a so-called "eluviatic" weathering, cations and $SiO_2$ are washed out (good drainage) causing both a drop in pH and a low $SiO_2/Al_2O_3$=1:1. In this case the final weathering stage will be: oxides of aluminium and iron (bauxite, laterite).

In foot-hills and relatively low areas an "illuvial" weathering occurs resulting in an enrichment of cations and a rise of pH and $SiO_2$. The montmorillonite type is formed $SiO_2/Al_2O_3$ = 2:1.

The relation with the mother rock is illustrated by Brinkman (1976), who characterizes various sedimental areas in the Guyanas with the help of clay minerals.

## 2. Chemico-physical properties.

Generally speaking the more $SiO_2$ is present in the clay mineral, the more "active" it will be regarding adsorption of water, and cations, swelling and shrinkage etc.

A limited number of properties of special importance to dehydration will be discussed now.

## 2.1 Cation adsorption

Cation adsorption by clay minerals has been studied so well that we start with this subject.

Grim (1962) made the following table:

Table D1

Cation exchange capacity (C.E.C.) of clay minerals (me. per 100 g clay)
(after Grim, 1962 p.30.)

| | |
|---|---|
| kaolinite | 3 - 15 |
| halloysite 2 H2O | 5 - 10 |
| halloysite 4 H2O | 10 - 40 |
| montmorillonite | 80 - 150 |
| Illite | 10 - 40 |
| vermiculite | 100 - 150 |
| chlorite | 10 - 40 |
| sepiolite-attapulgite | 20 - 30 |

The chemico-physical mechanism of cation adsorption is explained by many authors.

The following is a citation from Hillil (1971, p 20 and 21).

"The attraction of a cation to a negatively charged clay micelle generally increases with increasing valency of the cation. Thus, monovalent cations are replaced more easily than divalent or trivalent cations. Highly hydrated cations, wich tend to be farther from the surface, are also more easily replaced than less hydrated ones. The order of preference of cations in exchange reactions is generally as follows (Jenny, 1932, 1938): $Al^{3+}$ $Ca^{2+}$ $Mg^{2+}$ $K^{+}$ $Na^{+}$ $Li^{+}$

When confined clays are allowed to sorb water, swelling pressures develop, which are related to the osmotic pressure difference between the double layer and the external solution (Aylmore and Quirk,1959) Depending upon their state of hydration and the composition of their exchangeable cations, clay paricles may either flocculate or disperse (Jenny and Reitemeier,1935). Dispersion generally occurs with monovalent and highly hydrated cations (e.g. sodium). Conversely, flocculation occurs at high solute concentrations and/or in the presence of divalent and trivalent cations (e.g., $Ca^{2+}$, $Al^{3+}$) when the double layer is compressed so that its repulsive effect is lessened and any two micelles can approach each other more closely.

Thus, the short-range attractive forces (known as the London- van der Waals forces) can come into play and join the individual micelles into flocs.

When a dispersed clay is dehydrated, it forms a dense and hard mass, or crust. On the other hand, when flocculated clay is dehydrated, if forms a crumbly and loose assemblage of small aggregates. Under rainfall action in the field, the dispersed clay will tend to become muddy, less pervious, and more highly erodible than flocculated one."

## 2.2 Watersorbtion

The difference in water sorbtion, due to the difference in "activity" of clay minerals had best be illusstrated by the Atterberg-values.

table D2 (after Grim 1962, page 218, table 5-1).

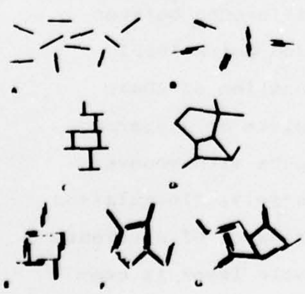
$$\text{"activity"} = \frac{\text{plasticity index}}{\% < 2\ \text{micrometer}} = \frac{\text{liquid limit-plasticity limit}}{\% < 2\ \text{micrometer}}$$

| | |
|---|---|
| montmorillonite | 0,5 -7 |
| attapulgite | 0,57 - 1,23 |
| illite | 0,23 - 0,58 |
| kaolinite | 0,01 - 0,41 |
| halloysite | 0,02 - 0,16 |

Apart from the clay mineral itself the adsorbed cations have a marked effect on the water sorbtion.

$Na^+$ and $Li^+$ couse the highest "activity" values, followed by $NH4^+$, $Ca^{++}$ and $Mg^{++}$, and then by $Al^{++}$, $H^+$, $Fe^{+++}$ and $Th^{++++}$.

Gillott(1968) made an interesting figure of the clay micro-structure as influenced by various chemicro-physical conditions. (fig. 2)



Modes of particle association in clay suspensions, and terminology. (After VAN OLPHEN, 1963, p.94.)

A. "Dispersed" and "deflocculated".

B. "Aggregated" but "deflocculated" (face-to-face association, or parallel or oriented aggregation).

C. Edge-to-face flocculated but "dispersed".

D. Edge-to-edge flocculated but "dispersed".

E. Edge-to-face flocculated and "aggregated".

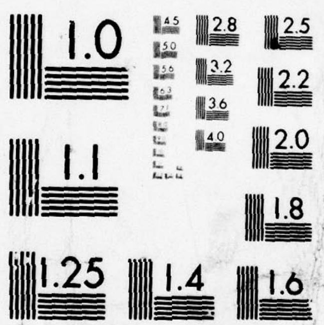
F. Edge-to-edge flocculated and "aggregated".

G. Edge-to-face and edge-to-edge flocculated and "aggregated".

AD-A074 219 ADRIAAN VOLKER DREDGING CO ROTTERDAM (NETHERLANDS) F/G 13/3
ASSESSMENT OF CERTAIN EUROPEAN DREDGING PRACTICES AND DREDGED M--ETC(U)
DEC 78 K D'ANGREMOND, J BRAKEL, A J HOEKSTRA DAJA37-75-C-0382
UNCLASSIFIED WES-TR-D-78-58 NL

3 OF 3
AD
A074219

END
DATE
FILMED
-10-79
DDC




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

The entire matter of water sorbtion in relation to other chemico-physical and micro-structural aspects is of great importance to the behaviour of spouted mud and its dehydration.

## 2.3 Permeability

The permeability of the soil mass is an important factor in connnection with dehydration.
Grim (1962) has given interesting data, which we recalculated from cm/min to the more convenient mm/d.

table D3 (after Grim, 1962, p.240, table 5-8).

| | | | | | |
|---|---|---|---|---|---|
| Quartz sand | | | | | 14,0 |
| " | " | : mica | | = 9:1 | 6,6 mm/d |
| " | " | : | " | = 7 3 | 6,0 |
| " | " | : | " | = 1:1 | 8,4 |
| " | " | : | " | = 0:1 | 7,0 |
| " | " | : kaolin. | | = 9:1 | 1,04 |
| " | " | : | " | = 7:3 | 0,10 |
| " | " | : | " | = 1:1 | 0,04 |
| " | " | : | " | = 0:1 | 0,04 |
| " | " | :Ca-Montm. | | = 9:1 | 0,06 |
| " | " | : | " | = 7:3 | 0,03 |
| " | " | : | " | = 1:1 | 0,008 |
| " | " | : | " | = 0:1 | 0,003 |
| " | " | :Na-Montm. | | = 9:1 | 0,002 |
| " | " | : | " | = 7:3 | 0,0004 |
| " | " | : | " | = 1:1 | imp. |
| " | " | : | " | = 0:1 | imp. |

## 2.4 Mechanical properties

The information through literature is large and interesting. We selected a few items which seem to have a special influence on dehydration.
Warkentin and Yong (1962) found a marked difference in shear strength and void ratio between montmorillonite and kaolinite clays with different pore water solutions.
The flocculated samples showed a higher strength than the dispersed ones in the whole. Kaolinite appeared to be stronger than montmorillonite.
Emerson (1964) found a marked difference in swelling of illite and kaolinite flakes, the first being 2-10 times larger than the second, depending on other factors, such as moisture pressure and soil solution.
Grim (1962) indicates that montmorillonite swells the most, followed by illite, and then by kaolinite. The strong swelling and shrinkage of montmorillonite clays is a very well-known fact in pedology (vertisols).Considerable earth shifts and even changes in the surface topography (sometimes cousing damage to constructions) are often found.

## 3. Dehydration and clay minerals

In this preliminary study decisive data,giving direct answers to the question of dehydration related to clay minerals, could not be found. Therefore, we confine ourselves to some preliminary remarks based on literature references and scattered experiencens.
In doing so, it should be always, kept in mind, that there are other factors of the same importance to the dehydration of spouted mud, such as

1. granulometry
2. soil solution (salt composition and concentration, pH etc)
3. cation-adsorption of clay minerals
4. organic matter (content, nature, and adsorption of cations and anions)
5. vegetation (evapo-transpiration)
6. Method of spouting and water removal (artificial drainage)
7. drainage conditions (geo-hydrology, topography)
8. climate

This renders predictions about dehydration, based on clay minerals only, useless.
Nevertheless, it is a generally found that the $SiO_2$-rich clay minerals (such as montmorillonite, and to a smaller extent, illite) can sorb more water than those with a low $SiO_2$-content, such as kaolinite.
This means that more water must be removed and under a higher tension for drying out montmorillonite, than is the case for kaolinite clays, while for illite this will lie between the two other clays.
However, once the soil mass begins to crack, the permeability and the evaporation surface increase enormously, which will occur particularly in montmorillonite clays.
Therefore, the general tendency is for the following to happen.
Kaolinite clays will settle rapidly into a rather high density and will dehydrate reasonably, after removal of the surface water. The shrinkage will be slight, and for this reason dehydration will proceed only slowly in the second phase.
Illite will dehydrate somewhat slower at the start, but once cracks and fissures occur dehydration will proceed quickly.
Montmorillonite clays will dry out slowly showing large shrinkage ratios; they will finally show wide cracks. In the latter stage - dehydration may be excessive.
If wetted again, the cracks will close through swelling. Consequently drainage will be very poor (as was frequently noticed in practice).
Table D4 illustrates the foregoing: the effect of other factors (granulometry, soil solution etc), has been included.

table D4 (preliminary dehydration test)
dehydration in 15 days

| soil type | clay mineral | % clay | % moisture loss | shrinkage % | El.cond. mS/cm |
|---|---|---|---|---|---|
| silt loam Iraq | kaolinite | 21,3 | 20,5 | 26 | 6,4 |
| silt loam Rott. port. | illite | 19,2 | 81,4 | 53 | 8,5 |
| silt, Limbourg | illite | 12,9 | 17,5 | 15 | 1,4 |
| clay Ethiopy | montmorillonite | 70,4 | 33,6 | 56 | 4,9 |

Apart from the marked influence of the clay mineral, the effect of salinity of the soil solution is noticeable especially for the harbour-mud from the Rotterdam port, influenced by a high $Na^+$- content (viz.par.2.2). Due to the complexity of matters, definite predictions about dehydration of a certain sample cannot be made at the moment.
A more detailed study will be necessary.

## 4. Climate

No literature references were found about the specific influence of climatic conditions on dehydration of spouted mud. One can say however, that, in general, the drier and the hotter the climate, the faster the drying. On the other hand, when drying proceeds too fast, an air dry crust will soon cover the underlying mud, hampering capillary rise and eraporation of soil moisture. In many cases salt cristals will be formed on the surface, helping to check evaporation and preventing development of vegetation.
It is well-known that weeds stimulate strongly the evapo-transpiration of soil masses and consequently the dehydration (Pons- and Zonneveld 1965, Willet 1972).
It depends, therefore, on many factors whether a dry and hot climate is favourable or not and what measures will be helpful to stimulate dehydration.

## 5. Conclusions and suggestions for further studies

A conclusion drawn from the foregoing is, that there are a few, very broad tendencies to be distinguished as regards dehydration of the various clay minerals.
The more "active" they are (montmorillonite) the more they sorb water, the more they need energy for drying and the stronger their shrinkage. The opposite can be said of the less "active" type (kaolinite), while illite is again in the middle. Dry and hot climates can be favourable to dehydration, as long as a crust is not formed. Such (salty) crusts severely hamper dehydration.
However the entire matter is very complicated because there are many factors that have an effect Especially the cation adsorption of the clay mineral is influential.

For a more detailed insight into the problem activities could be undertaken, namely four:

1. to collect practical information from dredging works systematically, including soil sample analyses.
2. to proceed with literature investigations.
3. to carry out large scale laboratory experiments with various natural and artificial soils.
4. to make field experiments i.e. taking various measures collecting the numerical results.

These four acticities are given in sequence of urgency, although the first two can srat at the same time.
On completion of the first and second activity, it should be possible to define a preliminary base for the practical job planning.

## Literature references


1. Hillil D: Soil and water, Academic Press, New York and London, 1971.

2. Mohr, E.C.J. and F.A van Baren: Tropical Soils, W. van Hoeve, The Hague, and Bandung, 1954.

3. Grim, R.E.: Applied Clay Mineralogy, New York, Toronto and London, 1962.

4. Gillott, J.E.: Clay in Engineering Geology. Elsevier Publishing Cy, Amsterdam, London and New York, 1968.

5. Brinkman, R.: A rapid reconnaissance of the main clay mineral provinces, in the Guyanas, "Geology en Mijnbouw", 46, 12, p.446-452, 1967.

6. Warkentin, B.P. and R.N.Yong: Shear strength of montmorillonite and kaolinite related to interparticle forces. "Clays and Clay Minerals", 9, p.210-217, 1962.

7. Emerson, W.W." The slaking of soil crumbs as influenced by clay mineral composition. Australian Journal of Soil Research, 2,2, p.211-217-1964.

8. Pons L.J. and I.S. Zonneveld: *Soil ripening and soil classification.* Int. Inst. for Land Reclamation and Improvement, Publ. 12, 1965.

9. Willet J.R.: Soil physical behaviour of spouted mud dredged from the Rotterdam ports (furrowing of Rotterdam mud deposits). Adviesbureau Arnhem BV 1972. Translation from Dutch article in "de Ingenieur", Februari 1972.

APPENDIX E: DEVELOPMENT OF BEARING CAPACITY OF HYDRAULICALLY TRANSPORTED SAND*

1. The stability of the sand surface, expressed in the CBR,** is found to depend on the density and on the degree of saturation. In Figure E1 the relation between the CBR and the degree of saturation is given for silty sand.

2. The degree of saturation of the sand surface of a hydraulic fill depends on the groundwater level and on the moisture retention of the sand. The latter can be determined from a diagram expressing the moisture suction relation or pF curve (Figure E2). In Figure E3 the ordinates represent not the imposed suction pressure, but the height above the free groundwater table. The agreement between suction pressure and height above water table is satisfactory for Dutch sands.

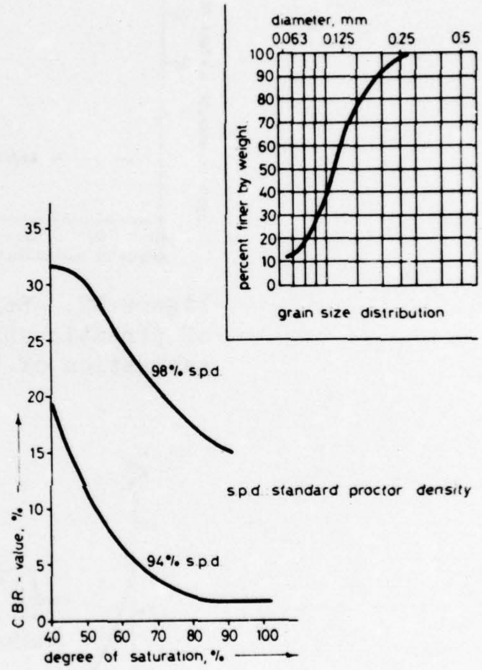



Figure E1. Relation between degree of saturation and CBR for a uniform fine sand

3. The groundwater level in a disposal area is determined by the geometry of the area, by the water permeability coefficient, and by the time. The change in groundwater level with time can be calculated analytically if certain assumptions are made:

- a. The subsoil is impermeable.
- b. Drainage occurs horizontally.
- c. The sand deposited as fill is homogeneous.
- d. The degree of saturation above the capillary saturated zone is constant (approximation indicated in Figure E2).

* By J. D. Nieuwenhius.
** CBR = California Bearing Ratio.

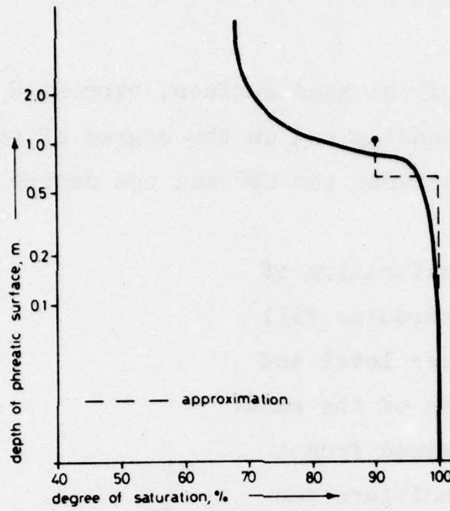



**Figure E2. Relation between depth of phreatic surface and degree of saturation of the surface of the fill**

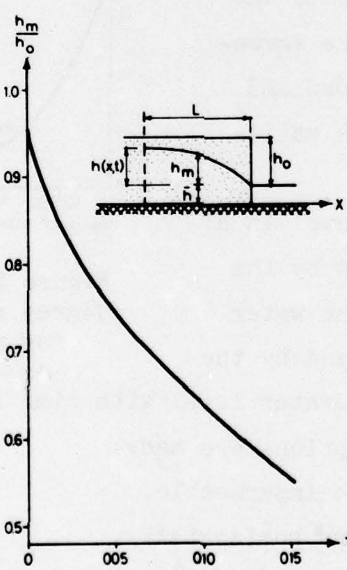



**Figure E3. Relation between mean ground level $h_m$ and a dimensionless variable T (Equation E3)**

*e*. No seepage occurs.

*f*. The disposal area has vertical sides and the verge ditches are directly adjacent to them (Figure E3).

4. The drainage problem is governed by the following linearized differential equation:

$$\frac{\delta^2 h}{\delta x^2} = \frac{n(1 - \bar{s})}{kh} \frac{\delta h}{\delta t} \tag{E1}$$

where

$h(x,t)$ = groundwater level

$x$ = horizontal coordinate

$n$ = porosity

$\bar{s}$ = mean degree of saturation

$k$ = permeability coefficient

$h$ = mean groundwater level in position and time

$t$ = time

Equation E1 corresponds to the one-dimensional heat and the one-dimensional consolidation equation so that solutions deduced from heat and consolidation theory can be for the boundary conditions.

$$\begin{aligned} 0 < x < L: &\quad h(t = 0) = h_o \\ x = L: &\quad h = o \end{aligned} \tag{E2}$$

the solution as given, for example, by Taylor (1948)* may be adopted:

$$h(x,t) = \sum_{m=0}^{\infty} \frac{2\, h_o}{m} \sin\left(\frac{M\, x}{L}\right) e - M^2 T \tag{E3}$$

* Taylor, D. W., Fundamentals of Soil Mechanics, John Wiley and Sons, New York, 1948.

where $M = \frac{\pi}{2} (mm + 1)$ and $T = k\ h\ t/n\ (1 - s)\ L^2$

Taylor gives $h(x,t)$ for $T = 0.05$ . Since here more particularly the initial drainage is of importance, Equation E3 has been tabulated for $0 < T < 0.05$ . The mean groundwater level $h$ (T) can be calculated with the aid of Equation E3; $h$ is given in Figure E3.

5. In principle, the road designer can, with the aid of analysis described above, estimate the stability development of his fill with the passage of time, provided that he has at his disposal a reasonably good correlation between the CBR values in the laboratory and trafficability by bulldozers on the site. The determination of the ratio between CBR and time is presented in Figure E4.

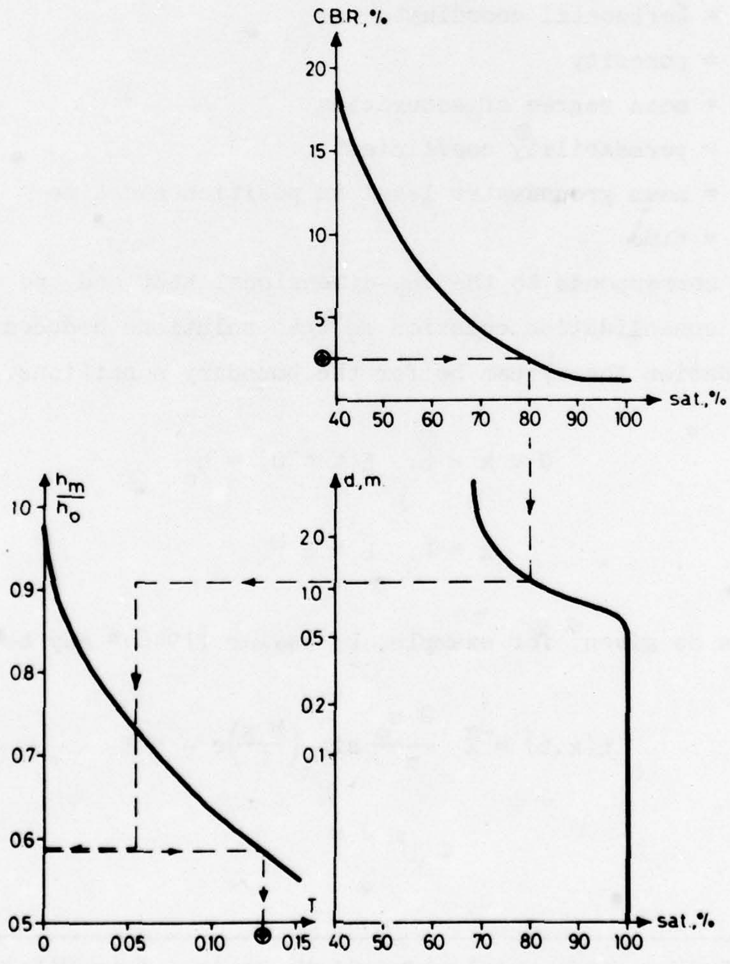



Figure E4. Relation between minimum CBR and T

## APPENDIX F: THE PHYSICAL, CHEMICAL, AND MICROBIOLOGICAL RIPENING OF THE SOILS IN THE IJSSEL-LAKE POLDERS

Reprint from : Smits, H et al.

*Physical ripening.*

The physical ripening of the soil mainly consists of three processes: —

*a.* the decrease in the water-content;
*b.* the formation of a macro-structure as the effect of crack-formation and disintegration into small, cubic or prismatic elements;
*c.* shrinkage.

The water content of the soil before the polder has fallen dry depends upon the clay content, the humus content and the water factor, according to the formula: $A = 20 + n\ (L + 3H)$. This equation reads: $A$ = water content in grams of water per 100 grams of dry matter; $L$ = clay content in grams per 100 grams of dry matter; $H$ = humus content in grams per 100 grams of dry matter; $n$ = water factor.

The water factor of submerged Zuiderzee deposits is from 2.0—2.2. Fig. 1 gives a graphic representation of the relationship described above.

Sediments of an extremely recent date may have water factors varying from 2.5 to 3.5. Such sediments are very soft, and only a light weighting (for instance, as caused by a progressive sedimentation) will already bring about a certain displacement of water (fig. 2).

Recent sediments are loosely structured; they have a capacious soil skeleton with a good water-carrying capacity. In addition to these properties they invariably have extremely narrow pores, which will materially resist the displacement of water. As a result, the consistency of these soils will be relatively great. Ripened soils have smaller pore spaces, and so they have a smaller water-carrying capacity. In the larger spaces in the ground there is little resistance against the movement of water; however, if the larger spaces are filled with water, this will act as a lubricant, so that, in that event, the soil will have a consistency much smaller than that of an equally heavy unripened soil having the same water content.

As shown in figs. 3 and 4, the water content of the uppermost layer of the soil (0—20 cm) will soon be going down at a very fast rate. The deeper layers will follow next, and the decrease in the volume of water lost is much smaller here. It will now be realised that the drying out of the soil is brought about almost exclusively by evaporation and that the gravitational loss of water only takes place in exceptional cases.

This drying-out process of the soil is irreversible to a considerable extent (figs. 3, 4 and 5). This is of great importance. If the reverse were the case, the soil, naturally, at the end of each winter would be just as wet, soft, and impermeable as it was immediately after the water had been drained off.

The drying out of the soil — more in particular as regards the deeper layers —

is strongly affected by the presence of vegetation (fig. 3; table 1). During the first few years other important factors are the weather conditions and the prolonged presence of pools. Of lasting effect is the presence or absence of seepage, and to what amount it occurs (table 2). And, finally, it is the water content of the soil in the initial stage which is the deciding factor as to whether much or little water will be lost by the irreversible drying-out process (fig. 1).

This drying-out process can be very well illustrated with the aid of the decrease of the specific volumina of the soil as time goes by (fig. 6). Specific volume is the volume represented by 1 gram of dry earth in its natural position. At the outset specific volumes are high; they will go down as a result of the drying-out process, so that the drying process can be illustrated by means of the rate of degression of the specific volumina. It will be seen that the deeper layers are affected at a later date and have a higher end-value than those of the overlying layers.

The drying out of the soil will cause the formation of cracks. The formation of these cracks will considerably improve the permeability of the soil (fig. 7).

Crack-forming is controlled by the same factors as those that cause the soil to dry out. They are: the presence of vegetation, if any, the drainage conditions (table 3), seepage (table 4) and the clay content of the soil (fig. 7).

The effect of seepage is very considerable as regards the deeper layers, because the annual amplitude of the water content of these layers is only a small one (table 5).

In case seepage is absent, the drying process of the soil is generally restricted to a depth varying from 1.25 to 1.50 m below surface level (table 6). Even low seepage values will already reduce this depth to a considerable extent.

On an estimate the water-storage capacity of a soil with a clay content of 20 % will be about 25 mm after 3 years, about 50 mm after 6 years, and 100 mm after 12 years.

Furthermore, the drying-out process is attended with shrinkage of the soil. The rate of shrinkage of the several layers can be illustrated with the aid of the degression rate of the specific volumina (fig. 6). Another illustration of this effect is given in fig. 8. As is the case with the drying-out effect, the deeper layers will be affected at a later date than those at the top, nor will these deeper layers be affected by the soil-ripening process as much as those at the top.

*Chemical ripening.*

The Wieringermeer Polder was reclaimed from salt water. The desalinization of the soil by the excess of rainfall occurring as a regular feature of the Dutch climate, was one of the early soil-ripening processes and forming the introduction to other chemical transformations.

As was the case in the later reclaimed Yssel-Lake polders, however, the salt had already virtually disappeared from the soil by diffusion into the fresh water of the Yssel-Lake. The last remaining traces of salt are leached out soon after the water has receded from the seabottom (table 1).

The bluish-black colour of the virgin sediment is due to the presence of ferrous monosulphide (FeS). After drainage it will oxidize into iron sulphate ($FeS_4$), which, with the carbonate of lime in the soil ($CaCO_3$), is transformed into gypsum ($CaSO_4$). This conversion is attended with a change of colour of the soil from black to greyish-brown. This oxidation is a fast-acting process as regards the upper layers, but penetrates into the deeper layers at a much slower rate (table 2). In fully matured soils the depth of the completely aerated zone

is approximately 1½ m; in the North Eastern Polder, however, this depth has not yet been reached even after 15 years.

The aeration process is a result of the drying-out of the soil and reacts to the same factors (see Ch. I).

Besides iron-monosulphide, the soil contains also iron-bisulphide (pyrite) ($FeS_2$). This material is accountable for the black colour of the soil to only a small extent; the best it can do is imparting a grey tint. The monosulphide tends to be converted into bisulphide in course of time, and that is why the deeper layers are greyish rather than black.

Also pyrite oxidizes into iron-sulphate and is subsequently transformed into gypsum by the interaction with calcium carbonate. Table 4 illustrates the course of development of this conversion. At the start the process develops at a fast rate; later on it slows down considerably. The latter phenomenon is caused by the presence of pyrite in different forms, some of which will readily oxidize, whereas other forms again will not.

The gypsum formed is partly transformed by interaction with the Mg and Na cations of the adsorptive complex into magnesium sulphate and sodium sulphate ($MgSO_4$ and $Na_2SO_4$). Part of the gypsum remains intact, however, which has a favourable effect on the initially somewhat unstable structure of these young soils.

So much gypsum is formed as to cause the soil moisture to become saturated with it for a number of years to come; even solid gypsum is often found in a finely crystallized form. However, the gypsum still remaining will gradually leach out.

In soils which are in equilibrium with sea-water, about 40 % of the exchangeable cations is represented by sodium. As a result of the fact that the water in the southern part of the former Zuiderzee was only brackish, this percentage was only some 20 % before the water of the Yssel-Lake turned fresh. The reduction in salt content of the moisture in the soil before the sea-bottom fell dry (table 1) was already accompanied by a considerable drop in the percentage of exchangeable sodium (table 5). The further fall in this percentage is to be accounted for by the formation of gypsum already referred to above, of which the Ca-ions are exchanged against Na-ions, thus causing the transformation of Na-clay into Ca-clay. The exchange of magnesium is a slower-acting process than that of sodium.

Soils in equilibrium with sea-water have a high potassium content as well. This is partly dissolved in water, partly fixed in exchangeable form to the adsorptive complex. The desalinization of the Yssel-Lake water already mentioned before meant a considerable loss in potassium content. However, by the time the water has been drained off the sea-bottom, the potassium content is still considerably higher than that of a comparable ripened soil. When crops are grown after the polder has been reclaimed, without applying potassium as a fertilizer, which can be done with impunity for a certain length of time, the potassium content is bound to be reduced (see table 6).

Phosphate is not present in the soil in the solute state. As a result, the reduction in the phosphate content after reclamation will depend entirely on the extent of its deprivation from the soil by the crops grown, and on the quantity of phosphate fertilizer applied (table 7).

The recently formed soils in the IJssel-Lake polders have a calcium-carbonate content of about 10 %. As a result of the Dutch climate with its surplus rainfall, this content will be gradually reduced at a very slow rate. In point of fact this reduction in content goes on at such a slow rate that for centuries to come no detrimental effects are expected to result to agriculture.

*Microbiological ripening.*

In the trial polder at Andijk as well as in the Wieringermeer Polder and the North Eastern Polder the development of the total number of bacteria and of a number of physiological groups were investigated from the moment that the water had been pumped out, or the soils were still covered with water. In most cases the numbers were determined in the topsoil by the plate-method and in some cases by the dilution-method. This study had been made by HARMSEN from 1927 to May 1947 and continued afterwards by the present writer.

The development of the micro-organisms in the trial polder and the Wieringermeer Polder stagnated so long as the salt had not washed away and the soils had not been drained. Drainage, causing a better aeration, resulted in a large increase of the number of micro-organisms up to a level, however, that was distinctly lower than that of corresponding old arable soils. In the heavy drained soils of the trial polder the numbers reached a higher level sooner than in the drained clay loam soils of the Wieringermeer Polder due to the fact that young mud deposits were present in the trial polder, while the heavy soils in the Wieringermeer Polder contained mainly resistant humus. In both polders ploughing under of grain stubbles and other organic matter caused a further increase in the number of micro-organisms being noticeable for a long period so that in the following year higher numbers of bacteria and fungi were also found. In soils of the trial polder which had been provided with fresh organic matter normal numbers were already found three to five years after the removal of the water. On most cultivated soils in the Wieringermeer Polder however, normal numbers were found only after 5 to 8 years.

The most rapid development was obtained after incorporation of fresh organic matter in the form of green manures. Although the soils in the Wieringermeer Polder were not really poor in humus, the humus originally present was not easily decomposable. Therefore, a normal development of micro-organisms was not possible without the presence of fresh organic matter. In accordance with this fact the soils of the Wieringermeer Polder showed a strong need of nitrogenous fertilizers in contrast with the soils of the trial polder.

In the North Eastern Polder a normal number of micro-organisms was reached more quickly than in the Wieringermeer Polder because of the absence of large amounts of salt. In most cases normal numbers were found within 5 years on the reclaimed sandy and heavy soils. Just as in the Wieringermeer Polder the numbers increased consistently after drainage, cultivation and incorporation of fresh organic matter.

The ripening of the subsoil in these polders developed more slowly, as might be expected; after a few years, however, it too showed a steady progress.

The susceptible and exigent organisms, as the nitrifying organisms and *Azotobacter chroococcum*, showed a good development only after an improvement of the aeration and when enough fresh organic matter was available for the Azotobacters. In the trial polder enough rhizobia were present so that inoculation of legumes was not necessary. In the Wieringermeer Polder and North Eastern Polder, however, these bacteria were scarcely present or practically absent, especially *Rhizobium meliloti* and *R. lupini*. It proved to be necessary, therefore, to inoculate legumes to a large extent.

The chemical changes in the young soils are brought about for an important part by the activity of micro-organisms.

So long as the nitrifying organisms had not yet developed sufficiently, most of the available mineral nitrogen was present in the ammoniacal form.

The transformation of Na-clay into Ca-clay in the trial polder and Wieringermeer Polder was stimulated by sulphur-oxidizing bacteria, which in the drained soils oxidized the sulphides present in the soil, resulting in the formation of sulphuric acid, iron sulphate and iron disulphate. Most of the soils in the IJssel-Lake Polders are rich in $CaCO_3$. In combination with sulphuric acid, formed by the sulphur-oxidizing bacteria large amounts of gypsum were formed, by which Na-clay was changed into Ca-clay. For this reason no great difficulties have been encountered in connection with the structure of these soils.

Sulphur-oxidizing bacteria, however, were also responsible for the formation of the so-called „katteklei" (cat-clay) in soil devoid of $CaCO_3$, especially in the Wieringermeer Polder. In the North Eastern Polder cat-clay was found on a much smaller scale. Cat-clay has a highly acid reaction (pH 1.5 to 2) and a very bad structure on which plant growth is hampered or impossible.

In the first years especially the sulphur-oxidizing bacteria are responsible for losses of calcium by the formation of $CaSO_4$. In later years losses of calcium as soluble $Ca(HCO_3)_2$ are brought about by all kinds of micro-organisms due to the production of $CO_2$. The formation of nitrates by the nitrifying organisms also facilitates losses of lime. By the displacement of calcium other bases are exchanged from the adsorptive complex and replaced for an important part by calcium. Magnesium and potassium, which are released by the activity of micro-organisms from organic and inorganic compounds and transformed into soluble compounds, may be added partly to the adsorptive complex.

Micro-organisms play also an important role in the transformation of phosphate compounds. Phosphates may be mobilized by micro-organisms from minerals, salts and organic materials and transformed into assimilable compounds. For this reason losses via crops are facilitated by micro-organisms. Organic phosphate compounds put into circulation by micro-organisms are of importance because these are not fixed by aluminium and iron. On the other hand phosphate may be fixed directly by microbes, while the solubility may be reduced indirectly by microbiological processes by which alkaline compounds, or soluble iron and manganese compounds are formed.

Iron compounds being made soluble by bacteriological reduction processes may be displaced with the ground water and transformed in other places into an insoluble form by chemical and bacteriological oxidation processes. Sometimes this may lead to clogging of tile drains.

Micro-organisms are indispensable for the mineralization of organic matter and for the production of humus. Alterations in the content and composition of the humus are therefore brought about by micro-organisms. In some cases an improvement has been noted in the content and composition (higher N-content) of the humus in soils in the North Eastern Polder.

*The relationship between the ripening process and the cultivation of arable crops.*

The intensity of the drainage applied was the factor determining the rate of ripening of the soil.

During the period the ripening process of the top soil was still proceeding, it appeared when the land was being brought under cultivation, that with shallow ploughing the soil had better properties favouring the growth of crops than with deep ploughing, more in particular, as regards some highly sensitive plants.

In conformity with experience previously gained, it was found in the saline polders (the trial polder near Andijk, and the Wieringermeer Polder), that there was some variation in the susceptibility of crops grown in a saline environment.

Investigations made in the North Eastern Polder and in Eastern Flevoland revealed the fact that, during the ripening process, the practically desalted, virgin soil temporarily possessed some properties retarding the growth of only a few highly susceptible crops. However, after the land had been under cultivation for a certain period of time, but also if, before cultivating it, the land had been left lying covered by spontaneously formed vegetation, these properties were generally modified to an extent that would cause such sensitive crops to show no longer any appreciable deviations in growth. It was found that during the first few years after the water had receded soil conditions were extremely favourable for the occurrence of whiteheads (*Ophiobolus Graminis Sacc.*).

The virgin soil proved to be deficient in nodule-bacteria. As a result, during the first few years after the land had fallen dry, leguminous crops could develop normally only when each crop was enabled to form adequate numbers of root-nodules by inoculation with the strain of bacteria specifically needed by each crop individually. In course of time the need for inoculation began to fall off, be it at a considerably faster rate for some of the legumes grown than for others.

In addition to this requirement, in quite an early stage of the soil-ripening process in the North Eastern Polder and in Eastern Flevoland, some of the crops proved to have a proportionately great need for readily assimilable phosphates.

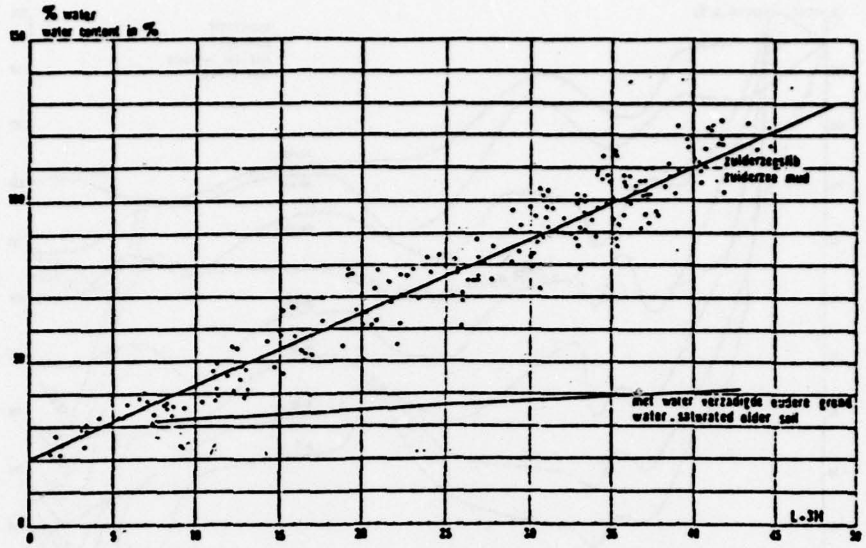



**FIG. 1.** Verband tussen lutum- en humusgehalte enerzijds (L + 3H) en watergehalte anderzijds bij Zuiderzeeslib en bij met water verzadigde 100 jaar oude grond

*Relation between clay- and humus content on the one hand (L + 3H) and water content on the other hand of Zuiderzee mud and of watersaturated soil, 100 years old*

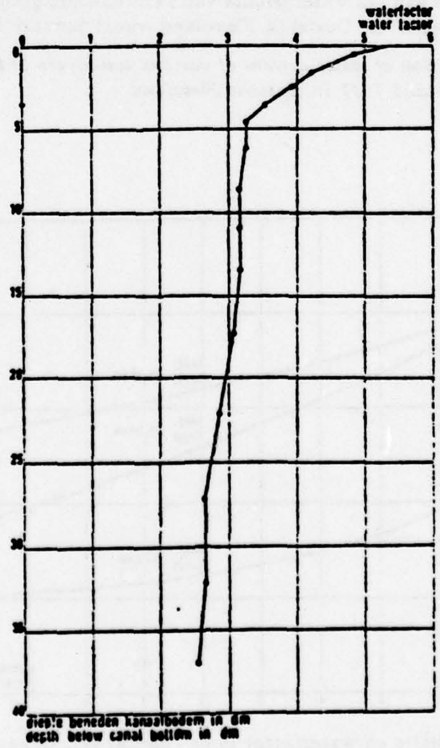



**FIG. 2.** *Water factors of extremely young canal-bottom mud in Eastern Flevoland in December 1957, related to L + 3H*

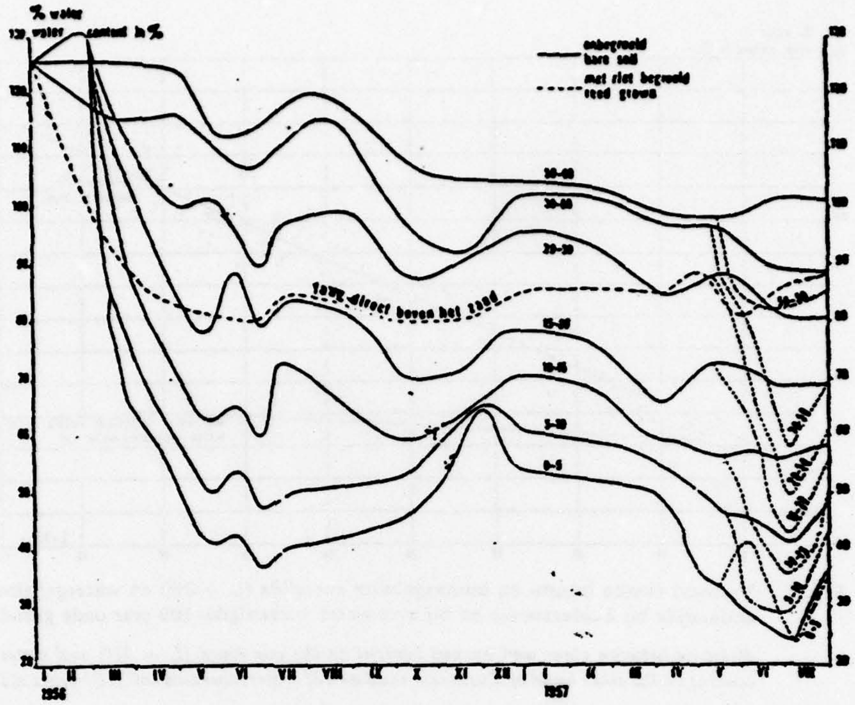


FIG. 3. Verloop van het watergehalte van verschillende grondlagen van het kleidepot „Het Spijk" in Oostelijk. Flevoland vanaf januari 1956 t/m juli 1957

*Diminution of water content of various soil-layers of the claydepot „Het Spijk" in 1956 and 1957 in Eastern Flevoland*

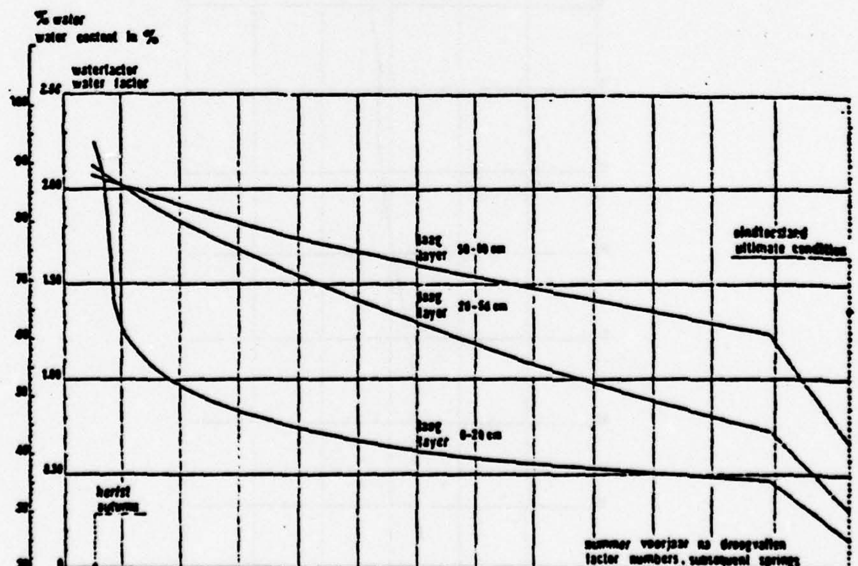


FIG. 4. Watergehalte en waterfactor in een aantal voorjaren na het droogvallen van een grond in de IJsselmeerpolders met 25 % lutum en 2.7 % humus, in de herfst drooggevallen

*Water content and water factor in subsequent springs after drainage of a soil in the IJssel-Lake polders containing 25 % clay and 2.7 % humus, which fell dry in autumn*

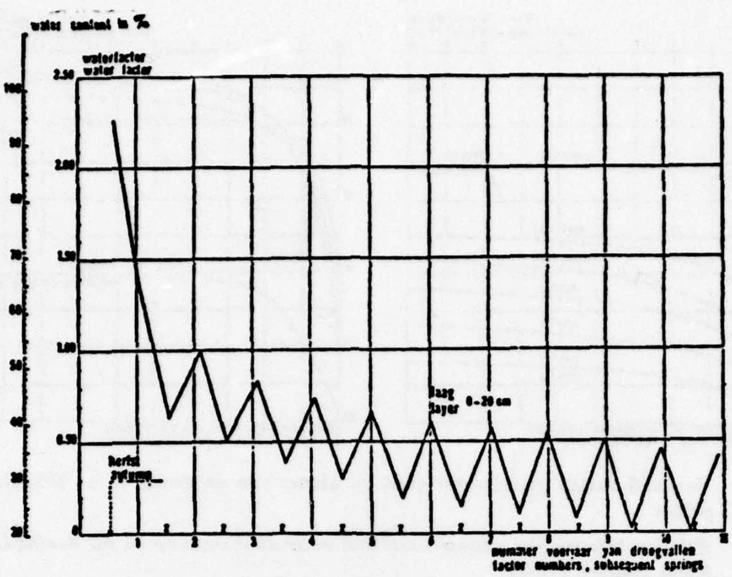



**Fig. 5.** Watergehalte en waterfactor in voorjaar en zomer van een grond in de IJsselmeerpolders met 25 % lutum en 2.7 % humus, in de herfst drooggevallen

***Water content and water factor in subsequent springs and summers of a soil in the IJssel-Lake polders containing 25 % clay and 2.7 % humus, made dry in autumn***

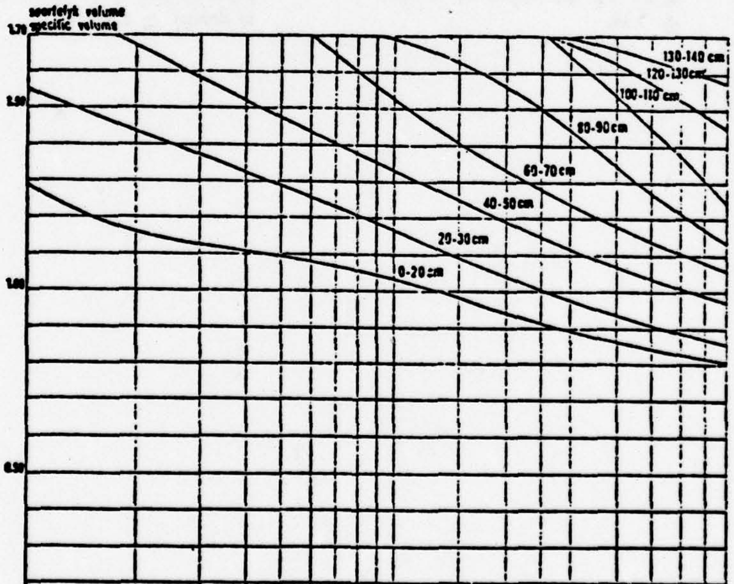



**Fig. 6.** Schematisch verloop van het soortelijk volume op verschillende diepten met de tijd van een grond in de IJsselmeerpolders met 40 % lutum

***Graph showing diminution of specific volume at different depths in course of time of a soil containing 40 % clay in the IJssel-Lake polders***

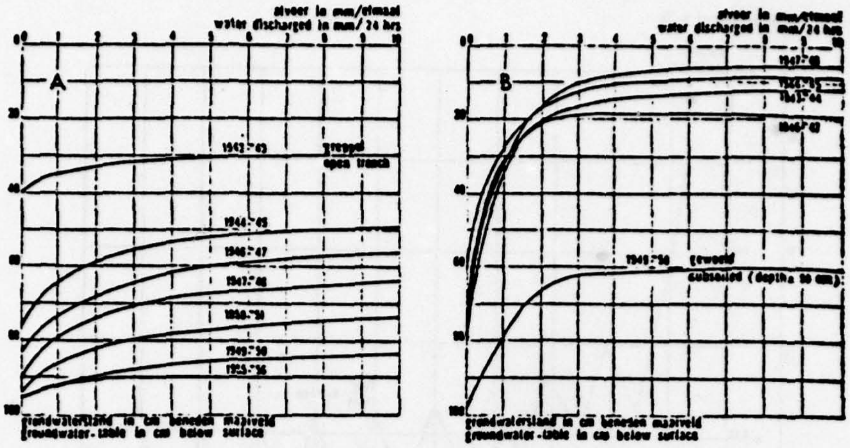



FIG. 7. Verband tussen grondwaterstand en afvoer van de drains in de Noordoostpolder

*Relation between groundwater-level and water discharged by the tile drains in the North Eastern Polder*

A. Zware zavel, gedraineerd op 12 m afstand; draindiepte ± 1 m.
*Loam B, drain pipes spaced apart 12 m; depth of drains ± 1 m.*

B. Lichte zavel (bouwvoor zware zavel), gedraineerd op 12 m afstand; draindiepte ± 1 m.
*Loam (topsoil loam B), drain pipes spaced apart 12 m; depth of drains ± 1 m.*

TABEL 1. Waterfactoren van grondlagen op verschillende diepten op een begroeide en op een onbegroeide plek op het kleidepot Het Spijk (3 juli 1957)

| Laag (in cm) | Begroeide plek | Onbegroeide plek |
|---|---|---|
| 0— 5 | 0.07 | 0.09 |
| 5— 10 | 0.22 | 0.51 |
| 10— 15 | 0.35 | 0.86 |
| 15— 20 | 0.54 | 1.15 |
| 20— 30 | 0.69 | 1.49 |
| 30— 50 | 0.92 | 1.61 |
| 50— 75 | 1.47 | 2.15 |
| 75—100 | 1.56 | 1.79 |
| 100—128 | 1.31 | 1.42 |
| *Depth of layer (in cm)* | *Plant-grown spot* | *Naked-soil spot* |

Waterfactor in uitgangstoestand (jan. 1956) ± 2.4

*Water factor at the start (Jan. 1956) ± 2.4*

TABLE 1. *Water factors of soil layers at various depths of a plant-grown spot and of a naked-soil spot in the clay-depot Het Spijk (3rd July 1957)*

TABEL 2. Waterfactoren van grondlagen op verschillende diepten op drie plekken met uiteenlopende kwelsterkten op kavel T 113 in de Noordoostpolder (voorjaar 1956)

| Laag (in cm) | Plek | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| 0— 10 | 0.5 | 0.6 | 0.5 |
| 10— 20 | 0.5 | 0.6 | 0.6 |
| 20— 30 | 0.7 | 0.6 | 0.8 |
| 30— 40 | 0.7 | 0.7 | 1.0 |
| 40— 50 | 0.8 | 1.2 | 1.4 |
| 50— 60 | 1.0 | 1.0 | 1.6 |
| 60— 70 | 1.1 | 1.4 | 1.9 |
| 70— 80 | 1.4 | 1.9 | 2.1 |
| 80— 90 | 1.4 | 2.3 | — |
| 90—100 | 1.7 | 2.5 | — |
| 100—110 | 2.0 | — | — |
| Kwel in mm/etm. *Seepage in mm/24 hrs.* | 0 | 0.04 | 0.41 |
| *Depth of layer (in cm)* | 1 | 2 | 3 |
| | *Spot* | | |

TABLE 2. *Water factors of soil layers at various depths of three spots having divergent seepage values in parcel T 113 in the North Eastern Polder (Spring 1956)*

| | Laag[1] | Scheurwijdte in mm | | | | Water-factor | Aëratie | | Kwel in mm/etm. | Zomergrond-waterstand[1] |
|---|---|---|---|---|---|---|---|---|---|---|
| | | < 1 | 1 t/m 3 | 4 t/m 6 | > 6 | | Volledig[1] | Onvolledig[1] | | |
| | 20— 40 | nootjes van ½ à 1 cm *nuts, sized ½—1 cm* | | | | 0.7 | | | | |
| | 40— 60 | 9 (68)[2] | 9 (97) | 1 (13) | 1 (13) | 0.9 | | | | |
| Plek 1 *Spot 1* | 60— 80 | 14 (146) | 9 (141) | — | 1 (20) | 1.25 | 0—75 | 75—106 | 0 | 202 |
| | 80—100 | 19 (145) | 1 (2) | — | — | 1.55 | | | | |
| | 100—120 | — | — | — | — | 2.0 | | | | |
| | 20— 40 | 4 (16) | 12 (45) | 1 (4) | — | 0.65 | | | | |
| | 40— 60 | 12 (115) | 15 (187) | — | — | 1.1 | | | | |
| Plek 2 *Spot 2* | 60— 80 | 9 (47) | — | — | — | 1.65 | 0—63 | 63—88 | 0.04 | 109 |
| | 80—100 | — | — | — | — | 2.4 | | | | |
| | 100—120 | — | — | — | — | — | | | | |
| | 20— 40 | 3 (22) | — | — | — | 0.9 | | | | |
| | 40— 60 | 5 (17) | 2 (4) | — | — | 1.5 | | | | |
| Plek 3 *Spot 3* | 60— 80 | — | — | — | — | 2.0 | 0—49 | 49—61 | 0.41 | 57 |
| | 80—100 | — | — | — | — | — | | | | |
| | 100—120 | — | — | — | — | — | | | | |
| | *Depth of layer*[1] | *< 1* | *1 to 3 incl.* | *4 to 6 incl.* | *> 6* | *Water factor* | *Complete*[1] | *Incomplete*[1] | *Seepage in mm/24 hrs.* | *Summer ground water table*[1] |
| | | *Width of cracks in mm* | | | | | *Aeration* | | | |

TABLE 4. *Data showing ripening condition of the soil-layers lying from 20 to 120 cm below surface level in three spots having different seepage values in parcel T 113 of the North Eastern Polder (Autumn 1955)*

[1] cm onder maaiveld
*cm below surface level*

[2] (68) = scheurlengte in cm
*length of cracks in cm*

| Scheurwijdte (in mm) *Width of cracks (in mm)* | Aantal scheuren *Number of cracks* | | |
|---|---|---|---|
| | Plek 1 *Spot 1* | Plek 2 *Spot 2* | Plek 3 *Spot 3* |
| $\frac{1}{4}$ en $\frac{1}{2}$ *$\frac{1}{4}$ and $\frac{1}{2}$* | 3 (40)[1] | 6 (30) | 8 (74) |
| 1 t/m 3 *1 to 3 incl.* | 1 (30) | 8 (113) | 15 (248) |
| 4 t/m 6 *4 to 6 incl.* | 1 (15) | 4 (107) | 5 (129) |
| 7 t/m 10 *7 to 10 incl.* | 1 (30) | 2 (37) | 0 |
| > 10 | 0 | 1 (9) | 0 |
| Waterfactor | 1.2 | 0.7 | 0.3 |
| Volledig geaëreerd[2] *Completely aerated* | 0—16 | 0—30 | 0—84 |
| Onvolledig geaëreerd[2] *Incompletely aerated* | 16—63 | 30—91 | 84—>120 |
| Zomergrondwaterstand[2] *Summer ground-water level* | 100 | 187 | > 250 |

**Table 3.** *Data showing state of ripening process of the soil-layer lying 20—50 cm below surface level in three spots with different drainage conditions in the Quarles Polder (Autumn 1955)*

[1] (40) = totale scheurlengte in cm.
*total length of crack in cm.*

[2] cm onder maaiveld.
*cm below surface level.*

| Diepte *Depth* | Indroging — Totaal (in mm) *Drying-out rate — Total (in mm)* | Indroging — Gemiddeld in mm/etm. *Drying-out rate — Average in mm/24 hrs.* |
|---|---|---|
| Gehele bodemprofiel *Total soil profile* | 145 | 0.97 |
| Bodemprofiel beneden 20 cm diepte *Soil profile below 20 cm depth* | 100 | 0.67 |
| Bodemprofiel beneden 40 cm diepte *Soil profile below 40 cm depth* | 60 | 0.40 |
| Bodemprofiel beneden 60 cm diepte *Soil profile below 60 cm depth* | 30 | 0.20 |
| Bodemprofiel beneden 80 cm diepte *Soil profile below 80 cm depth* | 10 | 0.07 |
| Bodemprofiel beneden 100 cm diepte *Soil profile below 100 cm depth* | 0 | 0.00 |

**Table 5.** *The drying-out rate of young marine-clay soils under cereal crops during the period of growth (150 days)*

| Laag in cm | Waterfactor |
|---|---|
| 75—100 | 0.66 |
| 100—125 | 0.84 |
| 125—150 | 1.00 |
| 150—175 | 1.32 |
| 175—200 | 1.46 |
| 200—225 | 1.44 |
| *Depth in cm* | *Water factor* |

TABLE 6. *Water factors at various depths in three Dollard polders average age of polders being ± 115 years*

| Laag (in cm) | Voorjaar na droogvallen | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 10 | 15 |
| | Aëratie *Aeration* | | | | | | | | | |
| 0—20 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 20— 40 | 2 | 3 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 40— 60 | 0 | 1 | 2 | 2½ | 3½ | 4 | 5 | 5 | 5 | 5 |
| 60— 80 | 0 | 0 | 0 | ½ | 1 | 2 | 2½ | 3 | 5 | 5 |
| 80—100 | 0 | 0 | 0 | 0 | 0 | 0 | ½ | 1 | 2½ | 4 |
| | Gescheurdheid *Crack-formation* | | | | | | | | | |
| 0— 20 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 20— 40 | 2½ | 3 | 3½ | 4 | 4 | 4 | 4½ | 4½ | 5 | 5 |
| 40— 60 | 0 | 1 | 2 | 3 | 3½ | 3½ | 4 | 4 | 4 | 4 |
| 60— 80 | 0 | 0 | 0 | ½ | 1 | 2 | 2½ | 3 | 3 | 3 |
| 80—100 | 0 | 0 | 0 | 0 | 0 | 0 | ½ | 1 | 2 | 2 |
| *Depth of layer (in cm)* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 10 | 15 |
| | *Spring following drainage* | | | | | | | | | |

TABLE 7. *The ripening of a loam-B soil-type (just over 20 % clay of the North Eastern Polder (aeration and crack-formation are shown graded into 5 types)*

Betekenis van de cijfers:
*Rating of numbers:*

Aëratie:
*Aeration:*

0 = geheel ongeaëreerd
*completely unaerated*
1 = 20 % geaëreerd
*aerated*
2 = 40 % geaëreerd
*aerated*
3 = 60 % geaëreerd
*aerated*
4 = 80 % geaëreerd
*aerated*
5 = geheel geaëreerd
*completely aerated*

Gescheurdheid:
*Crack-formation:*

0 = ongescheurd
*no cracking*
1 = scheurafstand meer dan 25 cm
*distance between cracks 25 cm plus*
2 = scheurafstand 10—25 cm
*distance between cracks 10—25 cm*
3 = scheurafstand 5—10 cm
*distance between cracks 5—10 cm*
4 = grove verbrokkeling (diameter meer dan 1 cm)
*lump-formation, coarse (diameter more than 1 cm)*
5 = fijne verbrokkeling (diameter minder dan 1 cm)
*lump-formation, fine (diameter less than 1 cm).*

## APPENDIX G : HEAVY METALS IN THE DUTCH DELTA, AN INTEGRATED PROGRAM FOR RESEARCH

By : Dr. A.J. de Groot (Delft Hydraulics Laboratory/Institute for Soil Fertility)

### I. Introduction

With the large rivers considerable quantities of heavy metals and other pollutants, among which phosphates and chlorinated hydrocarbons, are transported into the direction of the Dutch coastal area. A great deal of these substances is adsorbed on the suspended matter of the rivers. By nature as well as in consequence of activities of civil engineering (enclosure of river outlets and dredging of harbours), large quantities of the suspended matter, together with the attached pollutants, are retained within the delta.

Within this short communication a survey will be given on our research on the hydrodynamical and chemical behaviour of heavy metals, adsorbed by sediments, in our aquatic environment. These investigations have been carried out in a close cooperation between the Institute for Soil Fertility (Haren, Groningen) and the Delft Hydraulics Laboratory (Delft).

A more detailed treatise will be given on the uptake of heavy metals by agricultural and horticultural crops which are cultivated on dredge spoils used for land filling. The same will be done for the translocation of heavy metals in the food-chain soil-grass-cattle for our large area of river flood plains, which are subjected to heavy metal contamination as a consequence of high river floods during the winter and early spring.

The main work during the past concerned the study of freshly deposited sediments. Meanwhile, however, the program of research is devoted to a more complete examination of the aquatic ecosystem. Attention is paid in this respect to the several reservoirs (e.g. interstitial water and suspended matter) which can contain heavy metals. In cooperation with the Biological Department of the Netherlands Organisation for Applied Scientific Research (TNO) the biological aquatic reservoirs have been incorporated in these investigations. A short evaluation of this integrated program will be given at the end of this communication.

### II. Transportation and geochemical studies

The original studies on origin and transportation of fine grained sediments (to which the pollutants are mainly attached) concerned the use of Mn as a natural tracer (for West-European rivers the contents of Mn in their sediments vary considerably, comp. Ref. 1). In a later stage these examinations were perfected by the use of the methods of the isotope geochemistry. In a number

of estuaries mixing processes of terrestrial and marine material were studied on the basis of differences in C12/C13 and O16/O18 ratios (Ref. 2 and 3). It was possible in this respect to follow the flow path of clay minerals, organic matter and carbonates separately in the estuarine regions.

Attempts are made to raise the number of useful natural tracers by the use of activation analysis (multicomponentanalysis). The impact of several rivers on the sedimentcirculation in the North Sea is now studied in this way.

For sediment transportation studies on short distances, a broad laboratory investigation has been done on the use of activable tracers (Ref. 4 and 5). The application of Ta is a promising method in this respect.

In close connection with the sediment transportation studies, research is carried out on the occurrence and behaviour of heavy metals. At this moment 9 metals are considered in the Dutch delta: Zn, Cu, Cr, Ni, Pb, Cd, Hg, As and Sb. The investigations have led to a detailed picture of the distribution of the heavy metals over the deposits in rivers, estuaries and coastal areas (Ref. 6, 7 and 8). During these studies also information was obtained about the development of heavy metal pollution during the past 15 years. Alarming in this respect are the large increases of the Cd and Hg contents in our aquatic environment during this period.

The actual contents of 5 heavy metals in aquatic sediments from the Duch delta have been given schematically in Fig. 1. Besides metals, also the contents for P are given in this diagram. All contents of elements are expressed here as percentages of the relevant contents in the sediments of the Rhine river (upstream, as the river enters our delta).

For a better understanding of Fig. 1 we mention that the contents of heavy metals in sediments depend on the grain size composition. Linear relationships are found in this respect between metal contents and percentages of the fraction <16 µm. In Table 1 the heavy metal- and P-contents of Rhine sediments are given, as values obtained by extrapolation of the above mentioned relationships to 100% of the fraction <16 µm.

Table 1. Metal- and P- contents, expressed in ppm, in sediments from the Rhine (extrapolated to 100% of the fraction <16 µm.)

| | |
|---|---|
| Zn | 2900 |
| Cu | 600 |
| Cr | 1240 |
| Ni | 100 |
| Pb | 800 |
| Cd | 45 |
| Hg | 25 |
| As | 220 |
| Sb | 17 |
| P | $8 \times 10^3$ |

On the basis of Fig. 1 we will now focus our attention on the following regional problems, which are caused by activities of civil-engineering (excepted the heavy metal pollution on river flood plains).

1. Ketelmeer. Before 1932 the distributary Yssel carried 11% of the Rhine water (and of the suspended matter of this river) to the Zuider Sea, the latter being directly connected with the North Sea. In 1932 the tidal effects were withdrawn from this area by means of an enclosure dike, thus creating the fresh-water Lake Yssel.

As a consequence of the absence of tidal action, nowadays suspended matter of the river Yssel is settling in its mouthing area (Ketelmeer) in full possession of the heavy metals of sediments from the Rhine river. The impact of this phenomenon on the whole Lake Yssel is now subject of an intensive investigation.

Furthermore, apart from a direct transport of contaminated Rhine material to Lake Yssel, adsorption of heavy metals from the water to the suspended matter can take place, as a consequence of the long residence time of the Rhine water in Lake Yssel.

2. Hollands Diep - Haringvliet. The Haringvliet was originally one of the two main Rhine-estuaries (the other one is the sea way via the Rotterdam harbour). In 1970 the tidal effects were withdrawn from this estuary by means of an enclosure dam (as part of the well-known Delta Plan). A similar operation was carried out somewhat later in the Grevelingen area, south of the Haringvliet.

If we compare the amounts of the heavy metals in deposits from the inner side of the Haringvliet-dam (as compared with those of the Europoort), we find a similar effect as has been found in the Ketelmeer area. The increase in the heavy metal pollution of the Haringvliet, within a relative short period of time, gives rise to severe concern with respect to the environmental management of this fresh-water area.

3. Oosterschelde. The Oosterschelde, at this moment still in open connection with the sea, is up till now a relatively unpolluted area. In the very near future a decision will be made on the way in which this river outlet will be enclosed. The most probable solution will be a dam of such a construction, which still gives rise to a reduced tidal action in this area. It is a complex problem in how far such a construction affects the amount of pollution in the area.

4. Waalhaven - Europoort. The Rotterdam harbour region is now the main deposition area of contaminated Rhine material. The dredge spoils of the harbour basins are the more polluted, the more these basins are located to the east. As an example of a highly polluted area the Waalhaven is represented in Fig. 1. The Europoort, which is more directly exposed to the sea, contains sediments with heavy metal contents which are close to the material from the marine regions.

The consequences of disposal of the contaminated dredge spoils on land will be discussed in the next chapter. Especially the use of dredged material for agricultural and horticultural purposes will be treated more deeply. The set up of limitation criteria for heavy metals in arable soils may restrict the application of dredge spoils in this respect.

5. River flood plains. During the winter and early spring large areas along our main rivers are subject to flooding. The deposited material has a close relationship to the dredge spoils from the eastern harbours in Rotterdam, as well from a view-point of general chemical and mineralogical characteristics as from a view-point of heavy metal contamination. In the next chapter we will discuss the agricultural problems of these contaminated river flood plains subsequently to those of the dredge spoils.

## III. Agricultural use of dredge spoils and river flood plains

A more profound treatise will now be given on dredge spoils and flood plains. The Institute for Soil Fertility has performed extensive studies on the heavy metal contamination of these types of soil that are in agricultural use, and on the consequences of this contamination for heavy metal levels in plants and animals.

1. Dredge spoils. Part of the dredge spoils from the Rotterdam harbours, which have been dumped on land, may have an agricultural destination. The basic substance is a fertile young river clay that allows, after ripening, the cultivation of various crops. The fertility is in many cases adequate for cultivation of crops without amendment of P and K fertilizers.

The dredge spoils, however, are seriously contaminated with heavy metals and various persistent organic compounds, such as pesticide-residues and PCB's. In Table 2 the mineral composition of various dredge spoil derived soils is compared with the mean composition of Dutch river clay soils. As the metals are fixed predominantly to the fine-grained fractions, their concentration is correlated with the clay-content (particle size-fraction < 16μm) of the relevant soil.
The heavy metal levels of dredge spoils from harbours situated east of Rotterdam are considerably higher than the levels from the harbours nearer to the North Sea. The composition of the agricultural soils derived from these dredge spoils depend on the origin of the upper layers of the deposits.

2. Effects of heavy metals on agricultural crops cultivated on dredge spoils. The study of the effect of the contaminated dredge spoils on the growth and composition of crops is performed in two ways:
- comparison of heavy metal levels in crops on dredge spoils with those of crops on uncontamined clay soils
- the same in pot experiments under more comparable growth conditions.

The advantages of pot experiments are the uniform growth conditions; as a disadvantage may be considered the difficulty to translate the results of pot experiments to field conditions. Combination of the results of both approaches can give more convincing conclusions.
*Pot experiment 1:* Eight different crops (potato, radish, carrots, onion, lettuce, grass, French beans and summer wheat) have been cultivated in jars with dredge spoils of different composition, age and origin. As a reference two uncontaminated clay soils were included. The heavy metal contents of the consumable and of the vegetative parts have been estimated, and the ratio contaminated/uncontaminated ("accumulationfactor") has been calculated. The mean values of the accumulationfactors of the consumable parts of the crops on the investigated eight different dredge spoils are specified in Table 3.

Table 2 Chemical composition of dredge spoil deposits and of river clay

| | $CaCO_3$ | Org. matter | clay < 16 µm | Zn | Cu | Cr | Ni | Pb | Cd | Hg | As |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | % | % | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm |
| Dredge spoil 1 | 16 | 6 | 27 | 600 | 100 | 170 | 30 | 140 | 5 | 3.0 | 33 |
| Dredge spoil 2 | 14 | 13 | 50 | 890 | 160 | 280 | 40 | 210 | 11 | 4.7 | 47 |
| Dredge spoil 3 | 14 | 11 | 37 | 1700 | 260 | 510 | 50 | 290 | 11 | 8.3 | 108 |
| Dredge spoil 4 | 12 | 14 | 53 | 1200 | 220 | 460 | 55 | 290 | 15 | 9.2 | 68 |
| Mean river clay | | | | 90 | 25 | 80 | 40 | 30 | 0.4 | 0.2 | 13 |

Table 3 Accumulation factors[1] of foods cultivated on dredge material

| Foodcrop | Mn | Zn | Cu | Cr | Ni | Pb | Cd | Hg | As |
|---|---|---|---|---|---|---|---|---|---|
| Potato | 1.1 | 1.8 | 2.4 | 2.7 | 3.4 | 4.3 | 2.2 | 2.7 | 3.1 |
| Carrot | 0.8 | 2.4 | 2.0 | 16.3 | 1.8 | 4.3 | 7.5 | 3.0 | 2.8 |
| Radish | 0.7 | 2.6 | 1.9 | 3.2 | 1.2 | 4.1 | 4.4 | 6.3 | 3.6 |
| Onion | 0.6 | 2.5 | 1.4 | 1.4 | 2.2 | 1.0 | 11.9 | 3.4 | 2.3 |
| Lettuce | 0.4 | 2.5 | 1.8 | 18.8 | 1.1 | 1.1 | 4.9 | 2.5 | 4.7 |
| Grass | 0.4 | 5.2 | 2.8 | 4.8 | 2.0 | 1.5 | 5.1 | 1.3 | 2.4 |
| Wheat | 0.2 | 5.1 | 2.7 | 2.2 | 3.0 | 1.1 | 8.9 | 1.7 | 2.8 |
| French bean | 0.6 | 1.6 | 1.1 | 2.1 | 0.4 | 5.6 | 3.3 | 1.6 | 2.3 |

[1] $\frac{\text{Mean concentration in crop cultivated on dredge spoil soil}}{\text{Mean concentration in crop cultivated on reference soil}}$

Two effects have been observed:
- an increase of most heavy metal contents (Cu, Zn, Cr, Ni, Pb, Cd, Hg, As) and
- a distinct decrease of the manganese content.

In most crops symptoms of manganese deficiency are visible. This manganese deficiency is caused by the excess of zinc in the soil-plant system.

*Pot experiment 2:* In order to study the behaviour of the heavy metal absorption by the plant with and without induced manganese deficiency an experiment has been performed with wheat and oats as experimental crops on the same 8 + 2 soil species of the first trial. Manganese deficiency was treated in one half of the plants by spraying them with manganous sulphate. The symptoms disappeared, and the yield of the treated plants was significantly improved. From the preliminary analytical data it appears that the manganese treatment results in a decrease of Fe-, Zn- and Cu-content, both of straw and grain.

*Pot experiment 3:* An experiment is started in which is studied in how far the much less contaminated dredge spoils from the most western harbours of Rotterdam (Europoort) can be used to cover the more contaminated sediments. Five crops (wheat, carrot, lettuce, potato and grass) are cultivated on three dredge spoils (one less, two more contaminated) and two reference river clay soils. The Europoort dredge spoils have been rinsed untill free from excess of saline. The harvested crops will be analysed for heavy metals in order to check if the contents are within acceptable limits.

*Pot experiment 4:* Besides the heavy metals, the organochlorine compounds may form a risk for the agricultural crops. In a preliminary experiment two heavily contaminated sediments and one reference soil, without detectable organochlorine compounds, are involved. Experimental plants are corn (Zea mais), potato, radish, lettuce and grass. The harvest products will be investigated on all relevant pesticide residues.

*Field observations:* Several older dredge spoil deposits are in use for the cultivation of agricultural crops as: Brussels sprouts, barley, cole seed, grass seed, potato, sugar beet and summer wheat.

Samples of various crops have been analysed and compared with the results of pot experiments. The agreement between both is good.

3. Consequences for human health. There are no legal regulations available about the tolerable heavy metal levels in vegetable food. The World Health Organisation has given an evaluation about this subject, in which is concluded that in the daily diet in Western Europe the levels of Cd, Pb, and to a less extent Hg and As are near to the threshold value and should not be enhanced in any product. Several crops, grown on dredge spoil deposits, show alarming high cadmium and lead concentrations, and their cultivation should be restricted. In agricultural products used for animal nutrition (grass, wheat, beat leaves) some metal concentrations also exceed the tolerance levels. The composition of grass is relatively less contaminated, as will be illustrated in the next paragraphs.

4. River flood plains. In the Netherlands about 40,000 ha of grassland is subject to flooding by the river water in winter and early spring. The composition of the sediments differs from the material that is transported at normal river fluxes. At high river water discharges more soil- and bed-erosion products dilute the more contaminated original river sediments. The level of the heavy metals in the river flood plain soil is equal to the mean level of the dredge spoil soils, and lower than the concentrations of the sediments deposited at normal river fluxes in the fresh water tidal area. (Table 4).

Table 4 Heavy metal contents, expressed im ppm, of Rhine flood plain soil.

| Zn | Cu | Cr | Ni | Pb | Cd | Hg | As |
|---|---|---|---|---|---|---|---|
| 1000 | 160 | 300 | 60 | 210 | 10 | 5 | 50 |

5. Effects on the heavy metal contents of the grass. The grass growing on the river flood plains can be contaminated by absorption of heavy matals from the soil, and moreover externally by adhering soil particles. For animal nutrition both sources have to be taken into account.

The mean heavy metal composition of flood plain grass is estimated by averaging the results of seven monthly samplings in the grazing season at several farms during three years. In a representative part of each sample the external contamination was removed by rinsing the grass with a dilute detergent solution and with demineralized water. In this way the external contamination can be distinguished.

The resutls have been compared with those of grass samples from farms situated on uncontaminated river clay soils. Table 5 shows that the elements As, Cd, Cu, Hg, Sb and Zn are enhanced in concentration. The plant availability of metals in this calcarous soils is relatively poor, thus the increase in the grass contents is much less than the differences in soil composition.

Table 5 Mean heavy metal contents, expressed in ppm, of grass of Rhine flood plains and of reference soils

| | Zn | | Cu | | Cr | | Ni | | Pb | | Cd | | Hg | | As | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | - | + | - | + | - | + | - | + | - | + | - | + | - | + | - | + |
| Flood plain | 84 | 78 | 15 | 14 | 3.6 | 2.9 | 1.5 | 1.2 | 5.8 | 3.7 | 0.31 | 0.28 | 0.05 | 0.04 | 0.44 | 0.22 |
| Reference | 49 | 44 | 12 | 12 | 3.5 | 2.4 | 2.4 | 2.0 | 5.3 | 3.4 | 0.18 | 0.16 | 0.03 | 0.02 | 0.30 | 0.18 |

— = unwashed samples

+ = samples washed with detergent and water to remove adhering soil particles

6. Effects of contaminated grass on animal health. The cattle in the flood plain pastures is subjected to three forms of heavy metal contamination: grass; soil particles adhering to the grass; and soil ingested directly. Only a small part of the metals is absorbed in the digestive tract. The availablitity (digestibility) depends on diverse factors as: the chemical form, the solubility, and the conditions in the rumen of the cattle.

The overall effect can be studied by analyzing the organs of the animal in which metals accumulate. To this end liver, kidney and meat samples have been analyzed of 15 cattle from three farms, situated entirely in the flood plain area, and from 7 cattle from a reference farm. Because of the large biological variation between the cattle, as caused by different ratios, health and age, only large differences in heavy metals can be distinguished.

The result was in so far surprisingly, that no significant differences could be found between the cattle organs from the contaminated and from the uncontaminated pastures (Ref. 9). Apparently the cattle is well protected against these toxic components in their diet. For Hg it could be proven that this element occurs in soil and plant material in an inorganic form. From methylated Hg a rapid accumulation can be expected; the inorganic mercury is made insoluble in the rumen by the sulphides present in this organ.
Sheep, in contrast, are extremely sensitive for Cu excess. They die from chronic Cu-toxicity if the total ration of grass and soil contains more than 15-20 ppm Cu.

7. Criteria for heavy metals in soils. The heavy metal concentrations that can be tolerated in soils depend on the biological processes which are in consideration. Soil microbes are relatively unsensitive, the microbes active in root nodule formation of legumes, however, are very sensitive for excess of copper. The difference in sensitivity for Cu between cattle and sheep has been already mentioned.

There are no reliable soil tests to determine the plant available fraction of a metal in various soil types. In many institutes in the world fundamental work is performed on this subject. Important factors as pH, clay and humus content are studied in our institute. Kloke (see Table 6) has suggested a list of tolerable concentrations of

Table 6. Tolerance levels, expressed in ppm, in soils (According to Kloke, 1974)

| | |
|---|---|
| Zn | 300 |
| Cu | 100 |
| Cr | 100 |
| Ni | 100 |
| Pb | 100 |
| Cd | 5 |
| Hg | 5 |
| As | 50 |

A. Kloke: Personal communication at the Nato Science Committee Conference on Eco-toxicology, Mont Gabriel, Quebec, 1974.

toxic elements in soils, mainly on the basis of literature observations. Others have calculated the maximal tolerable gift of metal-containing waste products which gives no rise to decreases in productivity or quality. These draft tolerance levels all are specified for the most susceptible soil: the acid, sandy soil with low humus- and clay-contents. The dredge spoils, however, are very rich in humus, clay and calcium carbonate, and will be much less sensitive for heavy metal excess than the acid sandy soil on which the tolerance levels are based. Nevertheless, our pot experiments and investigations of crops in the field have demonstrated that several metals accumulate in the crops cultivated on that type of soil.

## IV. Evaluation of the examinations

In the preceding chapters special attention has been given to the heavy metal composition of deposited mud. The distribution of heavy metals in deposited mud has been demonstrated in Fig. 1. This insight is insufficient, however, if conclusions have to be drawn on the biological consequences of heavy metal pollution in an estuary or in a fresh-water basin. Another problem is how to predict the consequences of civil-engineering activities for the behaviour of heavy metals. In this type of research, which deals with cause and effect relations, an integrated hydrodynamical-geochemical-biological approach is necessary. In this connection the Institute for Soil Fertility and the Delft Hydraulics Laboratory are now co-operating with the Biological Department of the Netherlands Organization for Applied Scientific Research (TNO).

This integrated approach of the problem of heavy metals in the aquatic environment has been given schematically in Fig. 2.

The abiotic part of the system, which is demonstrated in Fig. 2, consists of 4 reservoirs with heavy metals. A river transports heavy metals in both soluble and solid forms (the latter indicated as suspended mud). Between these two forms a dynamic equilibrium can exist. Dependent on the hydrodynamical circumstances (reduced current velocities) and chemical processes (e.g. flocculation) a partial sedimentation of the suspended matter takes place, After sedimentation a large number of reactions occur, which result into a delivery of heavy metals to the interstitial water (mobilization). As a consequence of this mobilization the concentrations of certain metals in the interstitial water can differ considerably from those of the surface water. In consequence of a number of processes the heavy metals in the interstitial water can influence the composition of the surface water. It is the object of our present research to study these processes quantitatively. A first field research in this respect has already been carried out in the Oosterschelde area and in the estuary of the river Ems. In the laboratory we examine the adsorption-, desorption- and fixation-processes with the help of radiochemical techniques.

The relative contribution of the 4 abiotic reservoirs to the heavy metal burden of an organism will depend on the way of living of such an organism and on the ability of adequate physiological regulation mechanisms.

In Fig. 2 a rough classification has been made in organisms living in the water-phase, like plankton and filterfeeders, and in organisms living in the deposited mud, such as the meiofauna, worms and certain shell-fishes. For the marine environment the biologistst in our working-group use for field-studies on specific and selected locations at this moment the following organisms:

a. For the water-phase: the shell-fish *Mytilus edulis* and the weed *Fucus versiculosis*. b. Associated with the sediment: the shell-fish *Macoma balthica* and the worm *Arenicola marina*.

With these organisms a rather intensive research program, in close co-operation with hydrodynamical and geochemical examinations,has meanwhile been carried out in the area of the Oosterschelde. The organisms were collected in an unpolluted area in the Irish Sea and subsequently exposed to the environtment of the Oosterschelde. After fixed periods of exposition in the field the amounts of Hg, methyl-Hg, Cu and Zn have been measured in the organisms. In order to be able to interprete the field-data in a proper way, the field experiments were preceded by intensive toxicological laboratory research.

The results of the above mentioned biological examinations have been published in a confidential report to the Dutch Government, written in Dutch. At this moment we are not able to give further information on this subject.

## V. References


1. Groot, A.J. de (1964). Origin and transport of mud in coastal waters from the Western Scheldt to the Danish frontier. In: Deltaic and shallow marine deposits (Ed. L.M. J.U. van Straaten), 93-103.
2. Salomons, W., Hofman, P., Boelens, R., and Mook, W.G. (1975). The oxygen isotopic composition of the fraction less than 2 microns (clay fraction) in recent sediments from Western Europe. Mar. Geol. 18, M23-M28.
3. Salomons, W. (1975) Chemical and isotopic composition of carbonates in recent sediments from Western Europe. J. Sediment. Petrol. 45, 440-449.
4. Groot, A.J. de, Allersma, E., Bruin, M. de , and Houtman, J.P.W. (1970). Cobalt and Tantalum tracers measured by activation analysis in sediment transport studies. Isotope hydrology, IAEA Vienna, 885-898.
5. Groot, A.J. de, Allersma, E., Bruin, M. de, and Houtman, J.P.W. (1973). Application of activation analysis in sediment transport studies, particularly by Cobalt and Tantalum. IAEA Technical Reports Series No. 145, 151-166.
6. Groot, A.J. de (1973) Occurrence and behaviour of heavy metals in river deltas, with special reference to the riversEms and Rhine. North Sea Science, MIT Press, 308-325.

7. Groot, A.J. de, and Allersma, E. (1973). Field observations on the transport of heavy metals in sediments. Conference on heavy metals in the aquatic environment (Nashville). Prog. Water Technol. 7, 85-95.
8. Groot, A.J. de, Salomons, W., and Allersma, E. (1976). Processes affecting heavy metals in the estuarine sediments. In: Estuarine Chemistry (Acadimic Press), in print.
9. Heidinga, M.C. Driel, W. van, and Groot, A. J. de (1971). The accumulation of Mercury in the winter-bed of the Rhine. TNO-nieuws, 382-384.

21 juni 1976

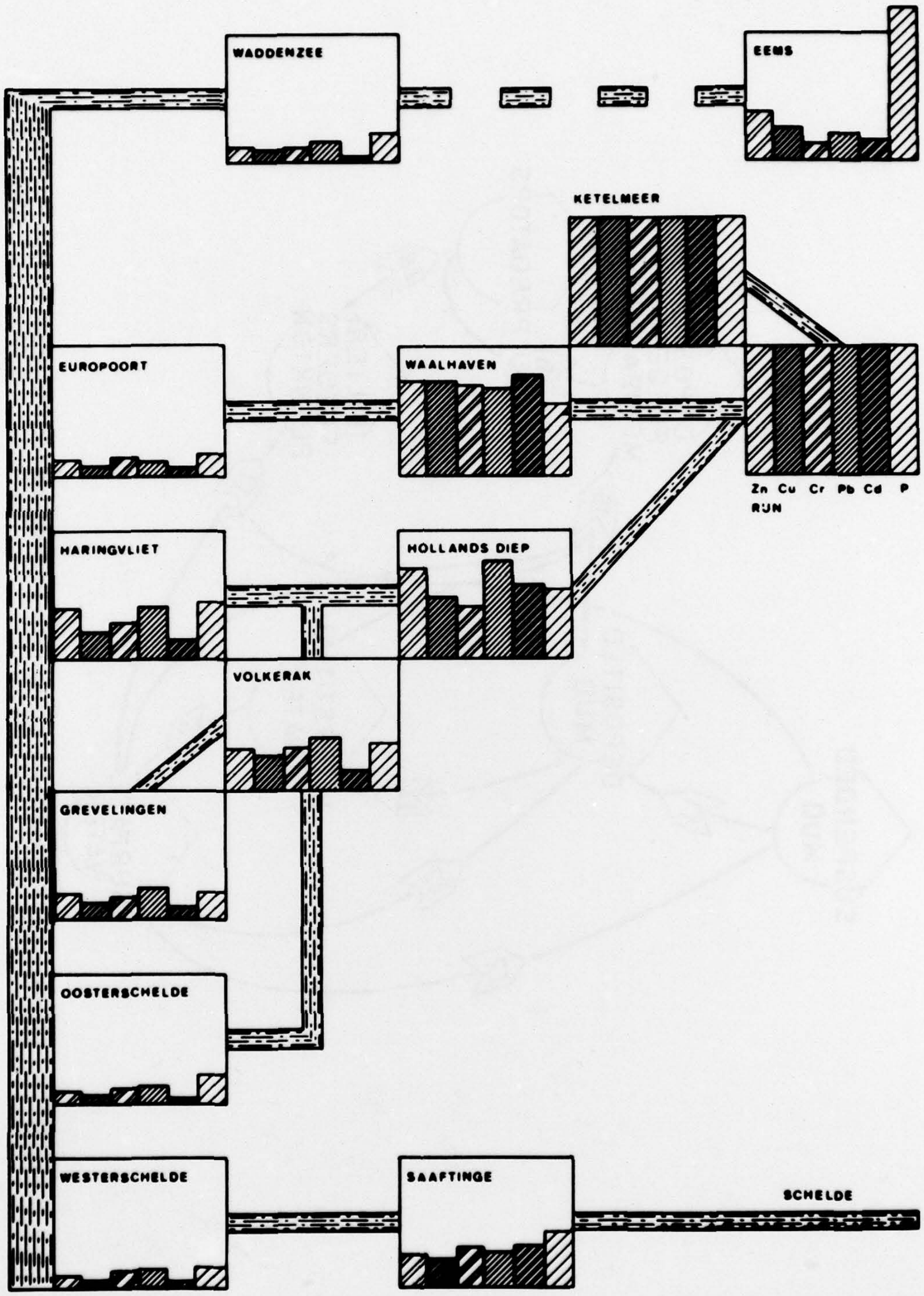



Fig. 1. Heavy metals and phosphate in sediments of the Dutch delta, expressed as percentages of the relevant contents in Rhine sediments.

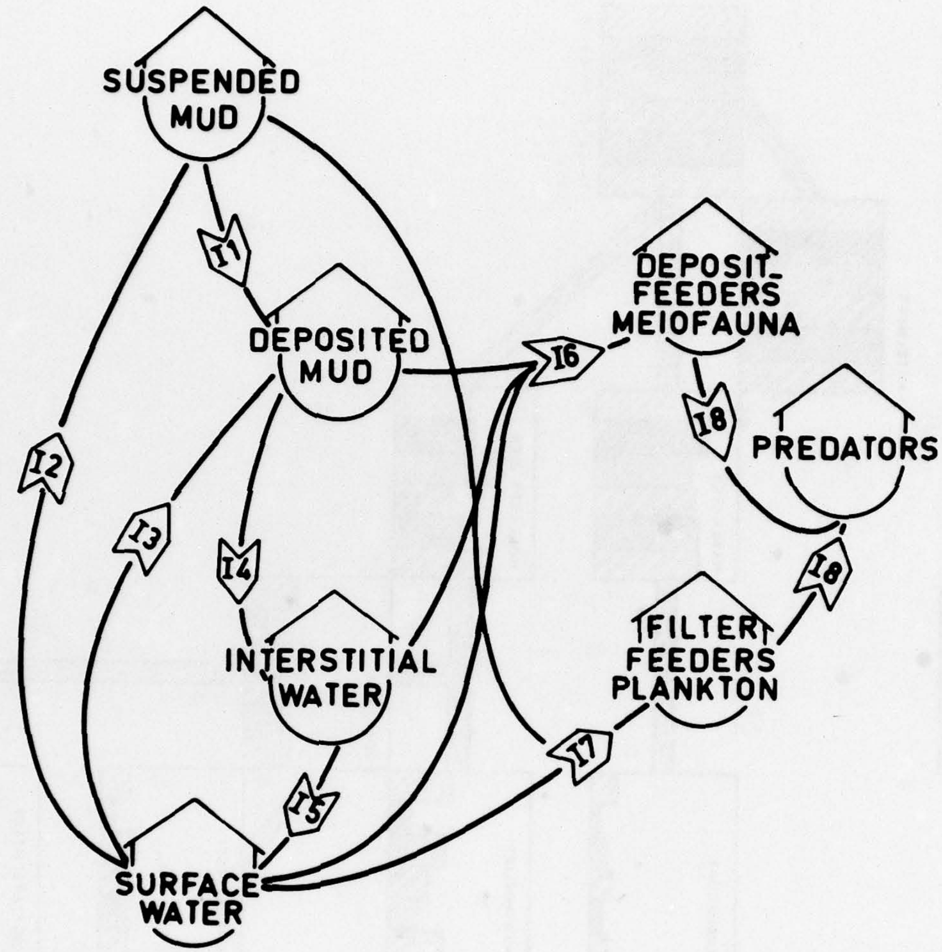



Fig. 2. Reservoirs for heavy metals and interactions between these reservoirs in an aquatic ecosystem.

# APPENDIX H: COMPOSITION OF HEAVY METALS IN ROTTERDAM HARBOR MUD IN 1972 AND 1974

Table H1

Chemical Composition of Rotterdam Harbor mud in 1972

| Sampling Location | $CaCO_3$ %[x] | Organic matter %[x] | % Fraction <16 μ Total Sample | % Fraction <16 μ Sample minus $CaCO_3$ | Heavy Metal Content, ppm[x] Zn | Cu | Cr | Pb | Cd |
|---|---|---|---|---|---|---|---|---|---|
| Rijnhaven | 5.8 | 1.2 | 3.6 | 3.9 | 211 | 20 | 67 | 36 | 2.5 |
| | 14.1 | 15.3 | 47.9 | 67.8 | 2070 | 404 | 949 | 463 | 39.1 |
| | 13.3 | 17.2 | 51.0 | 73.4 | 2294 | 459 | 1059 | 493 | 41.0 |
| | 14.2 | 14.4 | 48.7 | 68.2 | 1770 | 355 | 743 | 427 | 34.4 |
| | 14.0 | 16.6 | 54.5 | 78.5 | 2261 | 443 | 975 | 477 | 39.8 |
| | 15.4 | 14.7 | 55.9 | 80.0 | 1861 | 343 | 735 | 405 | 34.1 |
| | 15.5 | 15.5 | 54.1 | 78.4 | 1845 | 363 | 736 | 397 | 35.8 |
| | 15.4 | 15.7 | 55.0 | 79.8 | 1843 | 358 | 730 | 390 | 36.4 |
| | 14.2 | 15.8 | 39.0 | 84.3 | 1996 | 391 | 698 | 499 | 34.0 |
| | 13.3 | 21.3 | 58.0 | 88.7 | 2024 | 386 | 764 | 451 | 33.3 |
| Maashaven | 2.7 | 0.2 | 0.5 | 0.5 | 37 | 0 | 11 | 9 | 0.4 |
| | 9.3 | 8.7 | 34.6 | 42.2 | 1083 | 207 | 458 | 296 | 18.1 |
| | 12.6 | 11.2 | 43.0 | 56.4 | 1579 | 287 | 633 | 348 | 27.7 |
| | 9.5 | 6.8 | 17.6 | 21.0 | 680 | 111 | 286 | 224 | 9.0 |
| | 14.2 | 15.9 | 60.2 | 86.1 | 1995 | 414 | 845 | 421 | 37.8 |
| | 15.5 | 14.8 | 67.8 | 97.3 | 1840 | 346 | 718 | 406 | 30.6 |
| | 15.0 | 14.3 | 67.2 | 95.1 | 1710 | 335 | 708 | 400 | 28.7 |
| | 14.3 | 15.7 | 65.2 | 93.1 | 1980 | 364 | 729 | 439 | 30.0 |
| | 19.6 | 4.7 | 34.9 | 46.1 | 297 | 46 | 131 | 85 | 2.9 |
| | 13.0 | 13.0 | 42.6 | 57.6 | 1671 | 285 | 513 | 429 | 16.0 |
| Waalhaven | 19.7 | 4.3 | 39.8 | 52.4 | 147 | 22 | 101 | 28 | 1.5 |
| | 14.7 | 9.8 | 34.3 | 45.4 | 1239 | 209 | 555 | 269 | 18.6 |
| | 14.0 | 16.1 | 58.0 | 83.0 | 2190 | 430 | 975 | 481 | 33.5 |
| | 14.1 | 15.7 | 60.1 | 85.6 | 2102 | 417 | 969 | 453 | 34.1 |
| | 14.1 | 14.6 | 60.1 | 84.8 | 1589 | 362 | 808 | 422 | 30.3 |
| | 13.5 | 10.7 | 52.3 | 69.0 | 1316 | 215 | 449 | 295 | 17.8 |
| | 7.0 | 5.7 | 18.9 | 21.7 | 644 | 178 | 143 | 182 | 3.4 |
| | 14.7 | 10.0 | 53.3 | 70.8 | 911 | 145 | 332 | 235 | 12.0 |
| | 14.1 | 13.8 | 48.3 | 67.0 | 2628 | 260 | 1027 | 481 | 20.8 |
| | 12.3 | 13.8 | 57.4 | 77.7 | 1514 | 239 | 594 | 800 | 14.4 |
| Eemhaven | 11.9 | 5.2 | 23.3 | 28.1 | 539 | 81 | 203 | 117 | 7.2 |
| | 13.7 | 7.4 | 27.8 | 35.2 | 717 | 111 | 250 | 153 | 9.1 |
| | 14.3 | 9.4 | 41.7 | 54.7 | 981 | 164 | 357 | 206 | 12.8 |
| | 17.4 | 7.6 | 51.2 | 68.3 | 412 | 65 | 183 | 89 | 4.6 |
| | 11.8 | 12.8 | 55.3 | 73.3 | 363 | 54 | 141 | 88 | 2.3 |
| | 14.4 | 9.2 | 38.7 | 50.7 | 721 | 103 | 229 | 146 | 8.1 |
| | 13.4 | 13.6 | 63.7 | 87.2 | 1347 | 219 | 415 | 340 | 15.5 |
| | 11.5 | 14.0 | 47.6 | 63.9 | 1201 | 166 | 372 | 277 | 11.1 |
| | 12.0 | 11.8 | 34.1 | 44.8 | 661 | 81 | 191 | 141 | 6.3 |
| | 18.8 | 4.6 | 31.8 | 41.5 | 59 | 1 | 65 | 12 | 0.1 |
| 2e Petroleum-haven | 15.6 | 3.0 | 16.2 | 20.2 | 451 | 51 | 154 | 81 | 3.0 |
| | 15.9 | 12.0 | 46.6 | 64. | 1332 | 218 | 476 | 266 | 18.6 |
| | 16.8 | 9.7 | 42.3 | 57.8 | 931 | 135 | 301 | 190 | 12.6 |
| | 16.8 | 10.9 | 45.8 | 63. | 1020 | 150 | 317 | 214 | 13.7 |
| | 16.8 | 13.2 | 57.5 | 82. | 1252 | 190 | 384 | 264 | 17.4 |
| | 16.5 | 14.2 | 56.5 | 81. | 1274 | 206 | 393 | 277 | 17.8 |
| | 14.5 | 14.6 | 42.2 | 59. | 1273 | 189 | 311 | 324 | 11.2 |
| | 15.7 | 12.7 | 47.4 | 66. | 1104 | 175 | 354 | 236 | 14.3 |
| | 15.2 | 18.6 | 56.7 | 83. | 1388 | 230 | 410 | 303 | 17.0 |
| | 14.9 | 22.5 | 53.8 | 85. | 1419 | 233 | 352 | 304 | 14.6 |
| 1e Petroleum-haven | 12.2 | 3.7 | 18.8 | 15.2 | 418 | 37 | 146 | 77 | 6.3 |
| | 15.4 | 9.3 | 34.2 | 43.4 | 232 | 149 | 337 | 188 | 13.4 |
| | 15.9 | 10.3 | 34.2 | 46.4 | 898 | 145 | 317 | 176 | 12.7 |
| | 17.9 | 13.1 | 44.0 | 63.7 | 953 | 164 | 308 | 204 | 12.8 |
| | 16.1 | 16.1 | 49.2 | 72.6 | 1186 | 225 | 402 | 239 | 17.0 |
| | 14.4 | 17.1 | 41.2 | 60.1 | 1002 | 213 | 366 | 223 | 14.2 |
| | 16.9 | 14.1 | 46.0 | 66. | 1095 | 194 | 374 | 237 | 16.5 |
| | 20.3 | 14.2 | 50.8 | 77. | 1022 | 179 | 332 | 225 | 14.4 |
| | 20.0 | 13.9 | 45.3 | 68. | 950 | 172 | 313 | 210 | 13.2 |
| | 19.8 | 11.1 | 42.3 | 61. | 613 | 106 | 137 | 130 | 6.7 |

[x]Percentages refer to dry weight (105°C)

Table M1 : continued

| Sampling Location | $CaCO_3$ %[x] | Organic Matter %[x] | % Fraction (16 μ Total Sample | % Fraction (16 μ Sample Minus $CaCO_3$ | Heavy Metal Content, ppm[x] Zn | Cu | Cr | Pb | Cd |
|---|---|---|---|---|---|---|---|---|---|
| 3e Petroleum-haven | 11.7 | 2.2 | 8.1 | 9. | 303 | 32 | 102 | 33 | 3.5 |
| | 12.8 | 3.8 | 12.1 | 14. | 394 | 45 | 138 | 69 | 4.9 |
| | 10.9 | 2.2 | 8.6 | 9. | 220 | 27 | 72 | 38 | 2.1 |
| | 14.4 | 5.3 | 18.4 | 22. | 545 | 72 | 192 | 106 | 7.1 |
| | 17.0 | 8.0 | 34.7 | 46. | 757 | 110 | 273 | 157 | 10.0 |
| | 17.1 | 9.3 | 45.5 | 61.9 | 803 | 121 | 280 | 182 | 10.6 |
| | 17.9 | 11.1 | 51.8 | 73.0 | 914 | 142 | 353 | 206 | 12.6 |
| | 17.4 | 12.9 | 57.4 | 82.4 | 1068 | 166 | 385 | 235 | 15.3 |
| | 17.2 | 11.7 | 53.1 | 74.7 | 1037 | 163 | 378 | 234 | 13.8 |
| | 17.9 | 12.4 | 57.9 | 83.1 | 1032 | 157 | 376 | 229 | 15.6 |
| Botlek | 14.7 | 6.8 | 22.7 | 28.9 | 670 | 95 | 237 | 129 | 9.8 |
| | 12.6 | 4.6 | 17.9 | 21.6 | 420 | 51 | 140 | 69 | 4.3 |
| | 16.7 | 7.5 | 31.6 | 41.7 | 636 | 95 | 237 | 136 | 8.5 |
| | 14.3 | 5.7 | 26.6 | 33.3 | 551 | 71 | 168 | 112 | 5.3 |
| | 17.1 | 11.2 | 51.2 | 71.4 | 1050 | 175 | 392 | 232 | 16.5 |
| | 13.8 | 8.8 | 43.0 | 57.0 | 929 | 128 | 283 | 178 | 11.0 |
| | 13.8 | 9.5 | 45.6 | 61.1 | 1200 | 174 | 303 | 241 | 11.1 |
| | 17.4 | 11.8 | 56.9 | 80.4 | 1033 | 165 | 361 | 235 | 13.4 |
| | 17.1 | 11.3 | 60.2 | 84.1 | 1003 | 172 | 353 | 289 | 11.5 |
| | 25.9 | 3.8 | 23.1 | 36.7 | 343 | 298 | 137 | 103 | 3.8 |
| Europoort-Entrance | 19.8 | 6.0 | 42.4 | 57.1 | 386 | 38 | 143 | 79 | 1.8 |
| | 20.7 | 6.5 | 48.3 | 66.3 | 333 | 42 | 162 | 91 | 2.4 |
| | 21.2 | 7.0 | 49.4 | 68.8 | 348 | 42 | 167 | 97 | 2.3 |
| | 19.4 | 6.1 | 44.1 | 59.2 | 316 | 36 | 147 | 81 | 2.5 |
| | 11.1 | 1.4 | 10.7 | 12.2 | 38 | 5 | 50 | 13 | 0.4 |
| | 17.9 | 5.2 | 35.0 | 45.5 | 224 | 31 | 118 | 55 | 1.8 |
| | 19.5 | 6.3 | 40.6 | 54.8 | 320 | 43 | 155 | 89 | 2.7 |
| | 18.8 | 7.1 | 45.0 | 60.8 | 345 | 48 | 171 | 88 | 3.5 |
| | 15.0 | 6.9 | 45.2 | 61.0 | 363 | 50 | 169 | 85 | 3.4 |
| | 20.2 | 7.1 | 47.8 | 63.7 | 369 | 33 | 164 | 118 | 3.2 |
| Europoort-Calandkanaal | 20.0 | 7.2 | 31.2 | 70.3 | 436 | 65 | 189 | 120 | 3.6 |
| | 18.2 | 6.5 | 47.3 | 62.8 | 353 | 52 | 172 | 91 | 3.2 |
| | 17.5 | 6.2 | 44.0 | 57.7 | 329 | 52 | 165 | 79 | 2.6 |
| | 17.6 | 3.6 | 46.3 | 60.3 | 304 | 49 | 143 | 76 | 2.0 |
| | 18.4 | 7.5 | 52.7 | 71.1 | 422 | 69 | 176 | 111 | 3.4 |
| | 17.0 | 4.5 | 38.9 | 49.6 | 146 | 22 | 101 | 34 | 0.8 |
| | 16.4 | 3.0 | 41.5 | 52.8 | 195 | 32 | 122 | 45 | 1.6 |
| | 16.2 | 5.4 | 48.7 | 62.1 | 215 | 38 | 127 | 63 | 1.6 |
| | 16.4 | 4.5 | 35.6 | 43.0 | 164 | 29 | 104 | 38 | 0.9 |
| | 14.7 | 3.2 | 38.4 | 47.9 | 232 | 46 | 129 | 61 | 0.8 |
| | 13.8 | 2.8 | 22.6 | 27.3 | 92 | 17 | 79 | 22 | 0.4 |
| | 16.3 | 4.2 | 39.3 | 49.7 | 133 | 19 | 94 | 32 | 0.6 |
| | 13.8 | 2.9 | 28.7 | 35.3 | 99 | 14 | 73 | 21 | 0.3 |
| | 14.3 | 3.2 | 25.3 | 30.7 | 111 | 14 | 70 | 21 | 0.4 |
| | 18.6 | 4.8 | 46.0 | 60.0 | 134 | 18 | 84 | 23 | 0.4 |
| | 4.6 | 0.3 | 1.8 | 1.9 | 28 | 0 | 12 | 5 | 0 |
| | 16.1 | 4.5 | 45.7 | 57.5 | 122 | 18 | 89 | 26 | 0.9 |
| Europoort-Beerkanaal | 18.9 | 5.6 | 39.9 | 52.0 | 227 | 28 | 122 | 63 | 1.7 |
| | 19.2 | 6.2 | 43.2 | 57.9 | 288 | 35 | 131 | 79 | 2.0 |
| | 18.3 | 5.3 | 38.8 | 50.8 | 237 | 30 | 151 | 65 | 1.6 |
| | 19.4 | 6.1 | 44.8 | 60.2 | 248 | 32 | 125 | 72 | 1.9 |
| | 17.8 | 4.5 | 36.1 | 46.5 | 170 | 23 | 98 | 48 | 1.0 |
| | 9.2 | 0.4 | 3.1 | 3.4 | 14 | 0 | 24 | 4 | 0.1 |
| | 12.4 | 2.2 | 14.9 | 17.4 | 86 | 7 | 53 | 21 | 0.5 |
| | 10.5 | 0.8 | 6.0 | 6.9 | 35 | 2 | 30 | 9 | 0.1 |
| | 12.2 | 2.0 | 12.7 | 14.8 | 74 | 4 | 45 | 17 | 0.3 |
| | 12.3 | 2.5 | 17.7 | 20.0 | 87 | 7 | 33 | 22 | 0.5 |
| Europoort-Beneluxhaven | 17.9 | 6.7 | 45.4 | 60.2 | 346 | 51 | 153 | 86 | 3.5 |
| | 18.3 | 6.5 | 46.9 | 62.3 | 356 | 51 | 154 | 91 | 3.3 |
| | 11.6 | 2.4 | 17.1 | 19.9 | 165 | 22 | 76 | 40 | 1.3 |

[x]Percentages refer to dry weight (105°C)

Table M2

Chemical Composition of Rotterdam Harbor mud in 1974

| Sampling Location | $CaCO_3$ %[x] | Organic Matter %[x] | % Fraction < 16 μ: Total Sample | % Fraction < 16 μ: Sample Minus $CaCO_3$ | Heavy Metal Content, ppm[x]: Zn | Cu | Cr | Pb | Cd | Ni |
|---|---|---|---|---|---|---|---|---|---|---|
| Waalhaven | 14.4 | 12.6 | 44.8 | 61.4 | 721 | 341 | 664 | 387 | 36.9 | 70.9 |
| | 12.9 | 14.3 | 49.5 | 68.0 | 122 | 406 | 710 | 484 | 42.5 | 82.2 |
| | 14.3 | 8.4 | 34.2 | 44.2 | 775 | 160 | 151 | 210 | 6.7 | 35.2 |
| | 14.0 | 11.7 | 49.4 | 66.5 | 489 | 294 | 502 | 342 | 24.8 | 59.1 |
| | 8.9 | 15.1 | 45.0 | 55.2 | 569 | 254 | 426 | 313 | 18.9 | 64.4 |
| Botlek | 16.5 | 5.9 | 25.3 | 32.6 | 621 | 97 | 229 | 153 | 11.5 | 30.0 |
| | 17.9 | 9.9 | 45.5 | 63.0 | 1028 | 168 | 357 | 231 | 19.0 | 48.5 |
| | 16.1 | 10.7 | 50.4 | 68.9 | 1011 | 175 | 343 | 222 | 18.7 | 49.4 |
| | 17.6 | 9.4 | 41.8 | 57.3 | 1002 | 171 | 353 | 235 | 18.9 | 43.6 |
| | 17.9 | 10.9 | 53.6 | 75.3 | 1097 | 191 | 339 | 242 | 19.2 | 52.3 |
| River KM 1010 | 15.9 | 9.1 | 3.1 | 41.5 | 1126 | 194 | 386 | 242 | 21.1 | 46.4 |
| | 15.6 | 7.7 | 27.0 | 35.2 | 932 | 154 | 311 | 209 | 17.3 | 39.0 |
| | 14.9 | 6.4 | 22.8 | 29.0 | 783 | 123 | 226 | 173 | 13.8 | 30.5 |
| | 14.3 | 5.2 | 18.2 | 22.6 | 622 | 98 | 229 | 143 | 11.1 | 27.7 |
| | 12.9 | 6.3 | 28.0 | 34.7 | 832 | 145 | 287 | 193 | 15.8 | 37.5 |
| River near Botlek | 11.1 | 1.7 | 7.0 | 8.0 | 208 | 27 | 87 | 43 | 3.3 | 12.6 |
| | 11.8 | 1.7 | 6.2 | 7.2 | 204 | 24 | 84 | 39 | 2.9 | 15.5 |
| | 13.3 | 3.0 | 13.6 | 16.2 | 366 | 54 | 144 | 85 | 6.4 | 18.5 |
| | 12.5 | 4.3 | 13.6 | 16.3 | 396 | 54 | 152 | 82 | 6.2 | 25.5 |
| | 9.6 | 1.6 | 7.0 | 7.9 | 206 | 27 | 88 | 61 | 3.2 | 10.5 |
| River KM 1021 | 11.2 | 1.7 | 7.7 | 8.8 | 200 | 24 | 83 | 40 | 2.7 | 10.3 |
| | 10.6 | 1.2 | 5.2 | 5.9 | 137 | 20 | 75 | 28 | 1.8 | 7.2 |
| | 11.6 | 2.0 | 8.0 | 9.3 | 182 | 24 | 84 | 39 | 2.5 | 11.2 |
| | 11.3 | 1.9 | 9.3 | 10.7 | 196 | 29 | 107 | 44 | 2.8 | 15.0 |
| | 9.9 | 0.6 | 3.6 | 4.0 | 98 | 12 | 60 | 20 | 1.2 | 6.7 |
| River near Europoort | 22.1 | 6.5 | 47.4 | 66.4 | 328 | 54 | 166 | 114 | 3.2 | 30.3 |
| | 21.9 | 6.1 | 44.8 | 62.2 | 294 | 46 | 154 | 108 | 2.9 | 27.7 |
| | 21.3 | 5.3 | 39.1 | 53.3 | 270 | 38 | 145 | 96 | 2.5 | 24.9 |
| | 19.7 | 4.9 | 33.3 | 44.2 | 249 | 36 | 132 | 86 | 2.6 | 22.7 |
| | 20.5 | 5.1 | 34.6 | 46.5 | 250 | 35 | 124 | 88 | 2.7 | 22.7 |
| SEA Disposal harbor-matęrial | 7.2 | 0.2 | 1.6 | 1.7 | 28 | 3 | 32 | 7 | 0.3 | 4.6 |
| | 6.6 | 0.3 | 4.2 | 4.5 | 28 | 7 | 28 | 6 | 0.3 | 6.1 |
| | 9.6 | 0.9 | 27.1 | 30.3 | 56 | 9 | 52 | 13 | 0.2 | 21.1 |
| | 6.0 | 0.2 | 1.4 | 1.5 | 20 | 3 | 24 | 6 | 0.1 | 3.3 |
| | 6.2 | 0.1 | 1.2 | 1.3 | 24 | 8 | 24 | 5 | 0.2 | 3.6 |
| SEA Disposal river-material | 12.2 | 1.6 | 9.0 | 10.4 | 95 | 12 | 60 | 26 | 1.1 | 10.8 |
| | 9.9 | 1.0 | 5.0 | 5.6 | 101 | 7 | 48 | 21 | 1.1 | 8.6 |
| | 11.6 | 1.5 | 8.5 | 9.8 | 83 | 10 | 60 | 26 | 1.0 | 9.7 |
| | 12.5 | 1.6 | 10.4 | 12.1 | 102 | 14 | 72 | 30 | 1.2 | 11.1 |
| | 16.2 | 2.8 | 18.8 | 21.2 | 152 | 24 | 84 | 50 | 1.5 | 15.2 |

[x]Percentages refer of dry weight (105°C)

## APPENDIX I: GLOSSARY

| Used in Report | U. S. Equivalent or Definition |
|---|---|
| Bucket dredge | Ladder dredge |
| Bund | Dike or embankment |
| Capital dredging | New work |
| "Eem" deposit | Geological formation in The Netherlands |
| Grab dredge | Bucket or grab dredge |
| Granulometry | Grain-size distribution |
| Lutum | Clay particles ($<2\ \mu$) |
| Make work with work | Working method aimed at a balance between quantities to be excavated and filled |
| Mud | Clay or silt or a mixture of both, with or without sand, having a water content higher than the liquid limit |
| pH-KCl | Acidity of soil, determined with the aid of KCl |
| Polder | Low-lying area where drainage is achieved by artificial means |
| Quaywall | Bulkhead |
| Rijkswaterstaat | The Netherlands equivalent of the Corps of Engineers |
| Ripening | A physical, chemical, and biological process which converts sludge (harbor mud) into soil |
| Spoil | Dredged material |
| Spouting | Process of filling an area (confined, unconfined, or submerged) with a mixture of dredged material and water from a pipeline |
| Suction pit | Pit from which a dredge is sucking material |
| Trunk | Junction of jetty or breakwater with shore |

# APPENDIX J: NOTATION

| | |
|---|---|
| $A$ | Water content as a percentage of the dry weight, and net power |
| $b$ | Capacity of organic matter to combine with water divided by capacity of the same weight of lutum |
| $c$ | Concentration by volume |
| $d$ | Grain size, m, and delivery pipe |
| $D$ | Dredging depth |
| $f$ | Coefficient of loss |
| $f(c)$ | A decreasing function of c |
| $F$ | Surface area of the basin, $m^2$ |
| $g$ | Acceleration of gravity, $m/sec^2$ |
| $H$ | Organic matter percentage |
| $L$ | Lutum percentage, and pumping distance |
| $n$ | Number |
| $p$ | Percentage of water combined with noncolloid material |
| $P_1$ | Air pressure needed |
| $P_o$ | Atmospheric pressure |
| $Q$ | Discharge, $m^3/sec$ |
| $Q_1$ | Quantity of mixture per second |
| $Qm$ | Density of the mixture |
| $Qw$ | Density of water |
| $T$ | Cycle time of the disposal area units, years |
| $v$ | Velocity of mixture |
| $X$ | Total area necessary for disposal of the dredged material, $m^2$ |
| $Y$ | Dredged quantity, $m^3/year$ |
| $Z$ | Thickness of a discharged layer, m |
| $\Delta H$ | Loss of head per unit distance |
| $\lambda$ | Coefficient of friction |
| $\nu$ | Dynamic viscosity, $m^2/sec$ |
| $\rho_k$ | Density of the grain, $kg/m^3$ |
| $\rho_w$ | Density of water, $kg/m^3$ |
| $\phi$ | Percentage of retention |

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

d'Angremond, K
  Assessment of certain European dredging practices and dredged material containment and reclamation methods / by K. d'Angremond, J. Brakel, A. J. Hoekstra, Adriaan Volker Dredging Company, Rotterdam, The Netherlands; W. C. H. Kleinbloesem, L. Nederlof, J. de Nekker, Rotterdam Municipal Works, Rotterdam, The Netherlands. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
  136, [94] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-78-58)
  Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Contract No. DAJA37-75-C-0382 (DMRP Work Unit No. 2C14)
  Includes bibliographies.

1. Assessments. 2. Containment areas. 3. Dredged material. 4. Dredged material disposal. 5. Dredges. 6. Dredging.

*(Continued on next card)*

d'Angremond, K
  Assessment of certain European dredging practices and dredged material containment and reclamation methods ... 1978. (Card 2)

7. Environmental effects. 8. Europe. 9. Reclamation. 10. Waste disposal sites. I. Brakel, J., joint author. II. Hoekstra, A. J., joint author. III. Kleinbloesem, W. C. H., joint author. IV. Nederlof, L., joint author. V. de Nekker, J., joint author. VI. Adriaan Volker Dredging Company, Rotterdam. VII. Rotterdam. Municipal Works. VIII. United States. Army. Corps of Engineers. IX. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-78-58.